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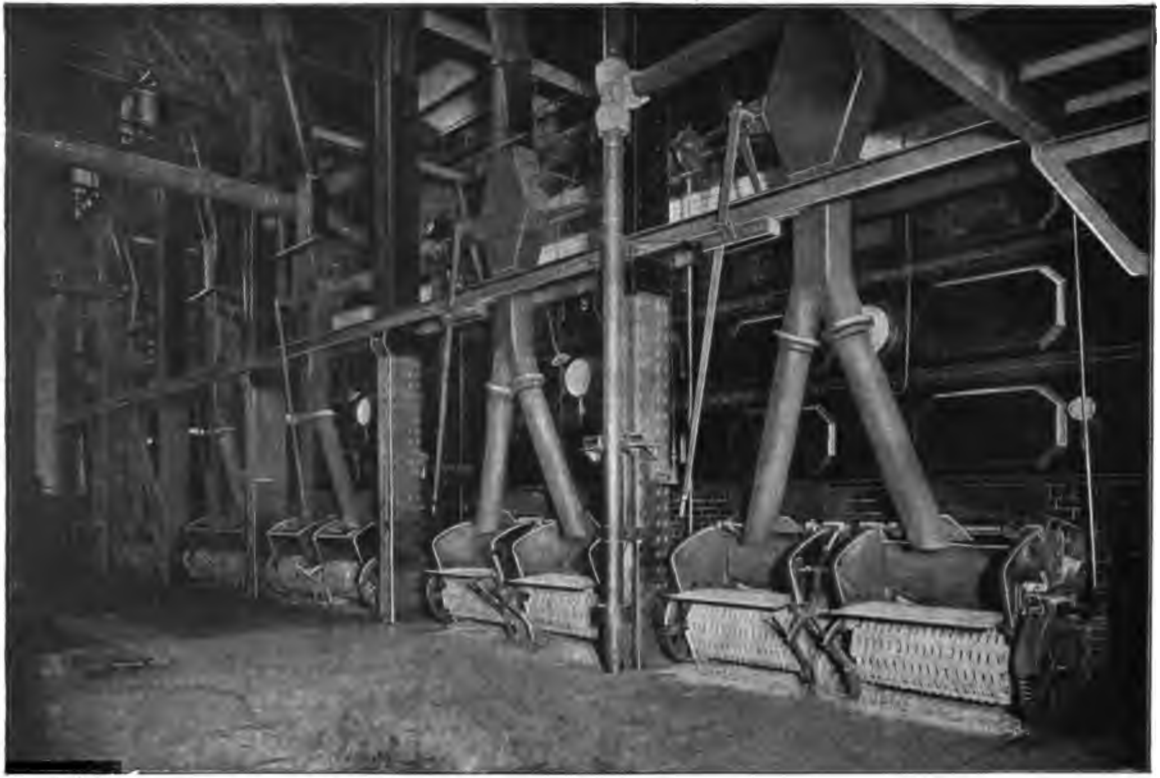

Frontispiece]

Part of Boiler House at the London County Council Tramways Generating Station, Greenwich.

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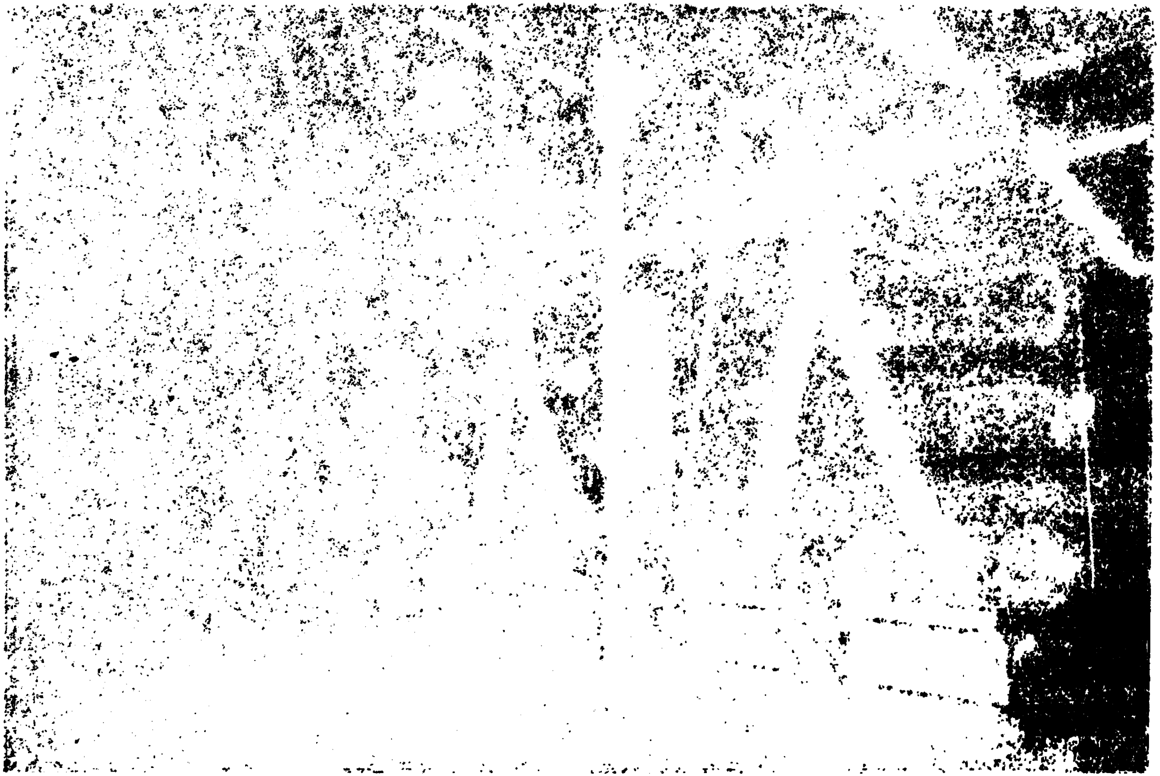

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EFFICIENT BOILER MANAGEMENT

WITH NOTES ON THE OPERATION OF REHEATING FURNACES

BY

CHAS. F. WADE, A.M.I.E.E.

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PREFACE

In deciding to write this small treatise the author was prompted to do so after having carefully perused the various articles in the Technical Press, pointing out the wasteful and inefficient manner in which the great majority of steam-raising plants are being worked in this country. Although these articles dealt in very great detail with the results that have been found on testing a large number of plants, yet there was practically no advice given as to how to set to work to improve matters.

In regard to books, there already exist many excellent treatises upon the scientific side of the chemistry of combustion, fuel analysis and so on, but all fail to deal to any extent with the practical application of the scientific principles of steam raising, so that the average engineer or works manager would understand it.

On the other hand, the practical textbooks deal very thoroughly with details and descriptions of boilers and accessory plant, with comparatively little attention given to the fundamental principles underlying their operation.

The author, who has had the handling and direction of many steam-raising plants, some of very large capacity and others small, both for electric power supply and for other industrial purposes, and has studied the question of economical use of fuel in all its different aspects, hopes that, in this volume, he will assist in filling a very obvious gap in the existing literature dealing with the practical side of steam boiler and furnace management.

The author has endeavoured to explain, in their proper sequence, the elementary scientific principles underlying the various sections which are combined under the heading designated by the title of this work, together with the systematic practical application of these principles so as to obtain the most efficient results.

Detailed description of the different plants and apparatus selected for illustration has not been attempted, this not being the object aimed at.

Although various typical examples of appliances have been selected in order to illustrate the text, and all these may be accepted as reliable and standard apparatus, it is not intended to imply that there is not any other equally or more reliable articles of the same class to be obtained elsewhere than those mentioned. All the apparatus illustrated, however, are of proved reliability, but no undue testimonial is to be understood by this.

The author wishes to express his great appreciation of the assistance rendered to him by his friend and colleague, Mr. Percy F. Lapworth, in reading, correcting and suggesting additions and improvements in the MS.

Also thanks and acknowledgments are due to the following firms in placing blocks, illustrations and various data at the author's free disposal—

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CHAS. F. WADE.

Sheffield, March 1919.

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EFFICIENT BOILER MANAGEMENT

CHAPTER I

Introductory.—Coal and its national importance—Notes on origin—Importance of economy from commercial and hygienic standpoints—The importance of efficient operation of boiler plant and steel-heating furnaces—Duties of those responsible for the consumption of fuel.

It cannot be borne too constantly in mind that coal is the absolute basis of every industry and everything that pertains to modern conditions of existence. There is no industry whatever that does not depend fundamentally upon the use of coal either directly as a source of heat for manufacturing purposes, or, as raw material in the production of various derivatives, and indirectly for the making of the necessary machinery and other appliances for the carrying on of other industries such as agricultural work, woodworking, etc. Coal is also the source of the greater part of our motive power for machinery in workshops, electric power stations, railways, etc. Until some other method of power production is successfully developed, such as the rise and fall of the tides, solar heat or other source of energy as yet undiscovered, coal will remain the foundation of our very existence.

Owing to the position into which this kingdom was placed by the war, we have been compelled to fall back upon our own resources for the production of such essential articles of commerce as dyes, and also chemicals, motor spirit, fuel oil and many other substances derived from coal-tar. Previously we had been dependent almost entirely upon Germany for the supply of these articles, particularly dyestuffs, and therefore it must be recollected that in burning coal in a wasteful and unscientific manner we are robbing these new industries of the raw material they require, which is absolutely lost when coal is burned directly in a furnace. If a great deal more attention is not paid to the efficient use of coal in the future than has been the case in the past, it is a dangerous possibility that the work in question will revert again to those countries where the scientific use of all their resources (and incidentally those of other countries) has been studied with successful results.

The Origin of Coal.—Nobody can state definitely, or even within some thousands of years, the age of the great accumulations of coal in various portions of the globe and with which these islands have been so richly endowed as a legacy from the remote past. There is no doubt, however, that coal is the more or less carbonised remains of extensive forests which flourished, died and decayed, and in course of time, either through convulsions of nature or the more gradual accumulation of other deposits, water borne or otherwise, became buried at varying depths below the present level of the soil.

At any rate, it is possible to trace the stages of coal formation which are exemplified in the degrees of carbonisation shown by the following substances, all of which are used to a more or less extent as fuel at the present time. Taking the deposits under consideration in the order of age, the oldest being last, we have—

(1) Peat.
(2) Lignite or Brown Coal.
(3) Bituminous Coal.
(4) Semi-Anthracite (Welsh smokeless).
(5) Anthracite.

These grades of fuel will be more fully described, and their composition and utility reviewed, in the following chapter, where the differences in composition will be dealt with.

From the commercial standpoint economy in the use of fuel is, of course, of great importance as a factor in the maintenance of low works costs. When the charges incidental to the handling of coal and ashes such as labour, wear and tear of plant, power required for handling, disposal of ashes, etc., are taken into account, it will be obvious how serious a factor in the balance sheet the fuel bill may be. Considering that the placing of a large contract may be decided (all other things being equal) by a very small difference in the amount of a tender, the bearing of the coal cost question will be readily realised. Again, the increase in demand for coal is likely to result in the maintenance of a high price per ton, which results in the penalising of the community generally, who may not be responsible for the unnecessarily large demand.

Investigations made by experts during 1917–1918 show an almost criminal waste of coal to be taking place by steam users, the whole of which may be put down to ignorance of the principles of economical coal utilisation, owing to the fact that this subject forms no part of the accepted course of training taken by the general engineer. Unless the engineer in charge of a boiler plant has a fair knowledge of the principles of economical steam-raising, he certainly cannot be entitled to consider himself as competent and skilled in this particular branch of engineering according to modern lights.

From the personal and hygienic point of view it must be remembered that the inefficient use of coal in the majority of instances results in the emission from chimneys of poisonous gases or other products injurious to health, whereas the complete combustion of coal gives rise to gases which, if not beneficial to health, are at any rate practically harmless. This will be more fully understood after reading Chapter III, which deals with the chemistry of combustion and allied subjects.

The importance of efficiency in the firing of boilers and other furnaces cannot be over-estimated when one realises the vast annual consumption in these two classes of plant. The working of steel-heating furnaces upon an efficient basis has hardly been considered, and if an economy of 20 per cent. is possible upon boiler plant alone, which, comparatively speaking, has received the closest study possible, the potential saving by the adoption of scientific methods of furnace firing and maintenance must reach an enormous figure. It is possible to see in modern steel-works boiler plant equipped and worked on the best scientific principles cheek by jowl with newly-built re-heating furnaces worked in a very inefficient manner.

It therefore behoves all those responsible in any degree for the consumption of coal, from the manager to the ash wheeler, to use their best and every effort to utilise every pound of coal to its utmost advantage. Otherwise we shall be rapidly overhauled by other more progressive nations in the race for commercial supremacy. Especially those who have the actual operation of boilers and furnaces under their care, whether in a supervisory or "working" capacity, should realise every minute of the day the responsibility which rests upon them, in more or less degree, for the maintenance of the national prosperity, with its resultant conditions of steady and remunerative employment and contentment, both industrial and personal.

CHAPTER II

COAL.—General composition and varieties—Utility of various classes of coal—Coke—Sizes of coal—Sampling of coal—The proximate analysis of coal and deductions therefrom—Calorific value of coal—Coal calorimetry—Importance of various tests.

COAL may be generally defined as combustible mineral matter formed originally of deposits of vegetable matter from primeval forests, which has undergone gradual carbonisation during the course of ages.

As used at present, coal may vary in age by many thousands of years, but the following divisions may be taken as fairly representing the various stages of formation.

DIVISION I.—PEAT

This is only mentioned and described in order to illustrate the sequence of development of the "true" coals. Peat consists largely of moisture and more or less decomposed and carbonised vegetable matter of various descriptions, giving an average "proximate analysis" as follows, after all moisture has been removed, viz.—

Volatile Matter	70 %
Fixed Carbon	28 %
Ash	2 %

As a fuel for industrial purposes, peat does not at present hold a very important position, although schemes for its wider utilisation are at present under consideration and may lead to wide developments.

DIVISION II.—LIGNITE OR BROWN COALS

Although there are considerable deposits of this fuel in various parts of the globe, there is only one small deposit in Britain, and it is consequently of little or no importance except as an illustration of the formation of coal, as it is older than peat but of more recent date than the true coals described in the following divisions. Lignite varies from an almost wood-like appearance to a black substance resembling pitch. Brown coal, as lignite is sometimes called, is the intermediate stage between the two extremes mentioned above, and on analysis gives approximately the following results (dry sample)—

Volatile Matter	50 %
Fixed Carbon	40 %
Ash	10 %

It will be noted that, as compared with peat, the analysis shows an increase of fixed carbon and a decrease in volatile matter; the ash varies in different samples from 1·5 % to 13 %.

Division III.—Bituminous Coals

This class forms the greatest and most important group of all the coals in use, either directly as fuel, or for the manufacture of gas, extraction of bye-products for various industries. Although the name of "bituminous" is given to these coals, and they are in fact universally known as such even by scientific men, the fact remains that they contain no bitumen whatsoever, although in the past it was believed that bitumen did form part of their composition.

Proximate analysis of bituminous coals give a very wide range of varying results generally as follows—

Volatile Matter,	from	24 %	to	43 %
Fixed Carbon,	,,	43 %	,,	73 %
Ash,	,,	1 %	,,	20 %

The general division of bituminous coals is further sub-divided into various classes, each of which has its particular sphere of utility and which will be discussed further in this chapter.

Division IV.—Semi-Anthracite

This coal, generally known as "Welsh smokeless steam coal," is somewhat similar in appearance to anthracite, and, as its popular name implies, is very largely used for steam-raising purposes, particularly in marine work. It is therefore of very considerable importance as a fuel. Its average analysis gives—

Volatile Matter	12 %
Fixed Carbon	82 %
Ash	6 %

Division V.—Anthracite

As far as is known, anthracite is the very oldest of the coal deposits, the carbonisation of the original vegetable matter having become almost complete, as is shown by the following analysis—

Volatile Matter	4 %
Fixed Carbon	90 %
Ash	6 %

It is mostly used for blast furnaces, but beyond this it is of little interest to the engineer.

The above divisions show clearly the stages of metamorphosis from vegetable matter to the almost pure carbon known as anthracite, but perhaps some reference should be made to—

Cannel Coal

This is used entirely for gas production, and its age approximates to that of the ordinary bituminous coals, although cannel is very different in behaviour and appearance. Its analysis shows in some cases—

Volatile Matter	63 %
Fixed Carbon	30 %
Ash	7 %

but its composition is very variable. The coals which are most nearly connected with the objects of this book are the various classes of bituminous coals and semi-anthracite, so a description of the varieties of the former group and their various uses will now be given.

Classification of Bituminous Coals

A useful classification of bituminous coals may be made as follows—

(1) Long-flame—free burning (non-caking)
(2) Long-flame—caking.
(3) Short-flame—caking.
(4) Short-flame—non-caking (semi-bituminous).

All these classes are used more or less for steam-raising, although the caking varieties should be avoided as far as possible, for the cohesive mass of coke formed prevents the proper passage of air through the fire-bed of the furnace, and thus reduces the possibility of complete and efficient combustion.

The long-flame caking coals (class 2) are most suitable for gas manufacture, the length of flame being a fairly good index of the quantity of gas.

The short-flame caking coals (class 3) are of most importance in connection with the production of metallurgical coke in coke-ovens and to a fair extent in steam-raising. For the latter purpose the coal should be selected which forms a coke that is easily broken up and not too hard and dense.

Long-flame free burning coals (class 1) are the best for use in furnaces, and are useful to a certain extent in steam-raising.

Coals in class 4 are known as semi-bituminous and are intermediate between class 3 and the semi-anthracite. They are the very best for steam-raising with a fair draught under boilers.

In selecting a bituminous coal for steam-raising purposes, other conditions being equal, that of the freest burning qualities should be favoured in conjunction with a moderate length of flame.

Although a general classification is given above, it must be borne in mind that there are innumerable degrees of variation within each class, each of which gradually merges into the next. Therefore the best method of selecting suitable fuel for any given purpose is to note its behaviour under working conditions, carefully noting results and combining this with the deductions obtained from proximate analysis and determination of calorific value.

Anthracitic, semi-anthracite or smokeless steam coal, to give its various appellations, burns with a very short flame and is quite smokeless in use. It requires a strong draught to burn but gives excellent results as to efficient combustion.

COKE

Coke is the residue of " fixed carbon " and ash which remains after all volatile matter (*i. e.* tar and gases) have been distilled off by heating bituminous coal to a bright red heat without access of air.

It burns smokelessly, but, of course, contains a very high percentage of ash compared with the coal. To obtain complete combustion sufficiently rapidly for steam-raising temperatures forced draught is required, and in this respect its characteristics are somewhat similar to semi-anthracite.

SIZES OF COAL

For firing boilers or other furnaces by hand, coal should never be used in pieces larger than that approximating to a 5-inch cube or small cobble size. Wherever possible it should be purchased in this size, as the breaking of coal by hand with a hammer leads to the production of a considerable amount of dust which falls through the grate bars and is wasted. Another objection to purchasing coal in the large sizes is that firemen are apt to use it direct from the bunkers without breaking it up, leading to the most inefficient combustion by closing the air spaces of the fire-bars and thus emitting large quantities of smoke and unconsumed combustible gases.

For mechanical stokers any size of coal, from 1¼ in. nuts downwards to smudge, is suitable, providing that the machine is designed to deal with the particular grades of fuel it is desired to use. In connection with this it is well to bear in mind that some forms of mechanical stokers, while operating satisfactorily with one grade of small coal, will need readjustment if another grade is to be fired; and it is not always possible to make this readjustment while the stoker is working, as it may necessitate a variation in the shape or size of some of the fixed portions of the machine.

THE PROXIMATE ANALYSIS OF COAL

By proximate analysis is meant the accurate determination of the proportion of moisture, volatile matter (*e. g.* gas and tar), fixed carbon, coke, sulphur and ash in a sample of coal.

In addition to obtaining an approximate idea of the value of the coal as a fuel, it is also useful as an aid to the better understanding of the changes which take place in a furnace when coal is burned.

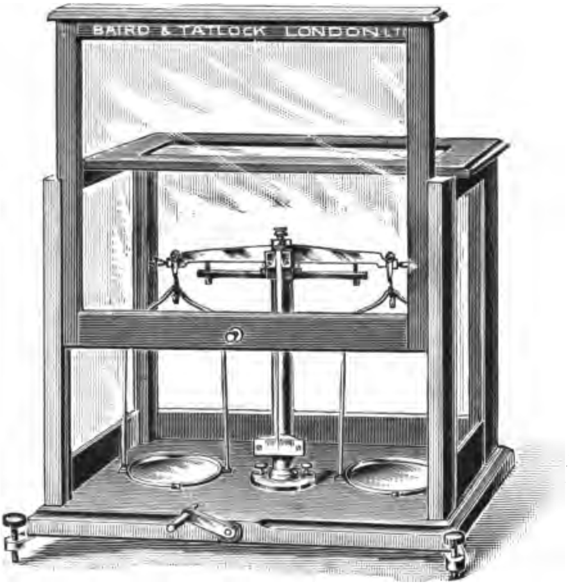


FIG. 1.—Chemical Balance in Case.

Before describing the actual procedure in making a proximate analysis it will be necessary to give a list of suitable apparatus for carrying out the various processes.

The Chemical Balance

The importance of the question of sufficient sensitiveness and accuracy of the balance used for analytical purposes must be given every consideration. A suitable balance, as supplied by Messrs. Baird & Tatlock, is shown in Fig. 1. It has agate planes and knife edges, is enclosed in a glass-windowed case with a sliding front (so that draughts may be excluded), and will turn to half a milligramme (·0005 of a gramme). A set of metric weights from ·001 to 10 grammes will also be required.

In selecting a suitable position for a balance, absence of vibration is the chief consideration, as with a sensitive instrument the slightest shaking will set it swinging so as to become quite useless. Where vibration cannot be entirely avoided it can be absorbed by placing the balance on a wooden board supported on the bench by rubber tennis balls. These, of course, must rest in suitable sockets to prevent rolling about.

To set the balance, after carefully levelling it, the front of the case is closed down and the beam raised by means of the external handle provided. Note is taken as to which way the pointer swings on the scale at the base of the pillar, and the adjusting screws at either end of the beam are regulated until the pointer remains stationary over the centre line of the scale when the beam is raised.

In using the balance, coal or any other substance must not be placed direct into the scale-pans. A piece of glazed paper should be placed in one pan and note taken of its weight, or balanced by a similar piece of paper in the opposite pan. The coal is weighed on the paper and does not soil or damage the pans. Crucibles or silica dishes may be placed in the scale-pan direct.

In weighing a sample of coal or residue the weights should not be handled with the fingers but by means of the forceps provided in the box of weights.

When the sample of coal is weighed out it is usually required to measure out a fixed amount, and in this case the necessary weights are placed in one pan and the coal sample fed into the other until an equipoise is obtained.

In weighing residues of tests it is usual to place the sample in one pan and place a weight nearly approximately to what is estimated to be correct in the other; if balance is not obtained the next size smaller or larger from the box of weights is substituted, as the case may be. Then follow down through the box of weights one by one, leaving those in the pan which are not quite heavy enough to balance, until a point will be reached where perfect balance is obtained. The total weight is added up as the weights are replaced in the box.

Accuracy in weighing will be rapidly acquired with a little practice.

Always work the lifting lever gently and without jar, and this will preserve the knife edges and also assist in rapid determination of weights.

Gas Burners

Two or three ordinary Bunsen burners are needed—articles that do not need any special description.

Other Apparatus

The other apparatus indispensable for the purposes of fuel analysis are—

Copper oven with water jacket.
Thermometers reading to 220° F.
Porcelain crucibles with lids.
Desiccator.
Crucible tongs.
Iron tripod stand.
Pipeclay triangles.
Muffle furnace.
Silica dishes.
Coffee mill.
Iron pestle and mortar.
Sieve of sixty meshes per inch.

Each of these articles will be described in connection with their actual use set forth in the following instructions.

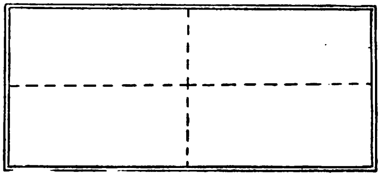


FIG. 2.—Quartering of Coal Truck.

Sampling of Coal

As the accuracy of a test in giving a correct idea of the quality of the whole of the coal contained, say, in a railway wagon depends entirely upon the way in which the initial sample is taken, it follows that the utmost care must be exercised in this process.

As the wagon is being unloaded, one shovelful of coal should be taken from the centre of each of the four rectangles obtained by quartering the surface as shown in Fig. 2. This should be repeated as each foot of coal is removed, as nearly as practicable.

The sample thus obtained must be placed on a clean iron plate and broken down to about the size of a walnut. It is then thoroughly well mixed with a shovel, arranged into a rough circle or rectangle and marked off with two lines at right angles so as to subdivide it into quarters. A sufficient quantity of coal should be taken at this stage and placed in an air-tight receptacle for test of the coal " as fired," this being the correct method when requiring calorific value tests in order to ascertain the efficiency of the plant.

One of the quarters of the heap is placed aside and the remainder is thrown away into the bunkers or fires. The coal that is left is broken up somewhat smaller, quartered again as before, and the process repeated until a quantity of about 2 lbs. is left, and this may be taken as a fair sample of the whole contents of the wagon.

Having obtained a fair sample as above described, we will now proceed to describe the methods of proximate analysis.

Air Drying

As the amount of free moisture may vary within very great limits according to the weather conditions encountered by the wagon in its journey from the colliery to the consumer, it is necessary to have some common basis for comparison of coals that eliminates the weather factor. This is obtained by *air drying* the sample before testing. The sample is broken to about "pea size," spread out on a sheet of clean paper in the laboratory and left thus for at least twelve hours. At normal temperatures all the moisture acquired in transit will have dried off during this period, and what may be taken as the normal condition of the coal is represented by this *air-dried sample.*

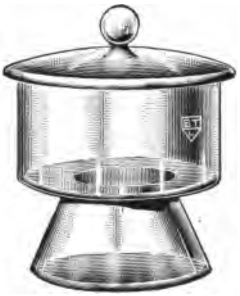


FIG. 3.—Desiccator.

The next stage in preparing the coal for analysis is to obtain a finely-powdered sample of the coal, and to do this proceed as follows. The whole of the sample of coal (about 2 lbs. weight, and of pea-size) is broken down to a coarse powder in the coffee-mill (which should be set to grind as finely as possible), and collected on a sheet of paper on the laboratory table. It is then thoroughly mixed and quartered in a similar manner to the original wagon sample until about 4 ozs. remains, which will be ample for all the following processes. Further pulverisation of the coal must be carried out with the pestle and mortar until *every particle* passes the 60-mesh sieve, otherwise the shale and harder portions of the sample will not be properly represented, thus leading to erroneous results.

Testing for Moisture

It is usual to make a test for free moisture in the *dry sample*—that is to say, the moisture that is abstracted by keeping the sample in a desiccator (Fig. 3) for such a period that no further decrease of weight takes place beyond a point determined by intermittent weighing.

Two grammes of the powdered fuel is weighed into a crucible and placed in one of the circular openings in the porcelain plate, and the whole is placed in the desiccator, the top rim of which has been well smeared with vaseline in order to make a perfectly air-tight joint with the lid. The well-bottom of the desiccator contains concentrated sulphuric acid for about half its depth, which, owing to its great " affinity " for water, will abstract all the moisture vapour from the contents of the vessel in which it is contained.

After one or two hours the crucible is weighed, and a slight decrease of weight will be noted; dry and weigh again at intervals until no difference is observed between two successive weighings. The difference between the weight thus obtained and the original two grammes gives the *Percentage of Free Moisture.*

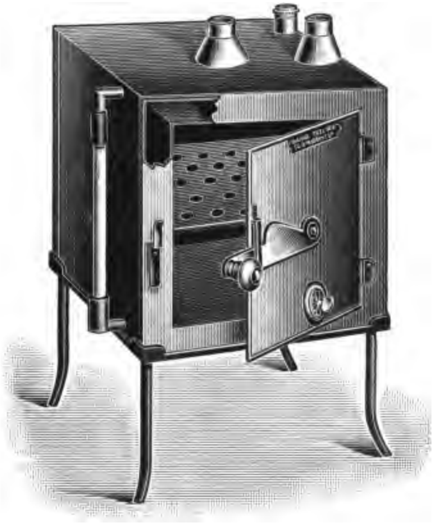


FIG. 4.—Water-jacketed Oven.

There still remains a certain quantity of moisture in the coal which can only be abstracted by the application of heat, and which is known in the United States and Canada as *Inherent Moisture.*

For determining this remaining moisture use is made of the water-jacketed oven (Fig. 4). The jacket is charged with water, a thermometer inserted in the pocket provided, and the apparatus heated until a temperature of 180° F. is indicated on the thermometer. The uncovered crucible must be placed in the oven as quickly as possible after weighing for free moisture, as the powdered fuel will absorb moisture from the air very rapidly. In fact, in all moisture tests it is preferable to keep a lid on the crucible whenever the sample is out of the desiccator or oven and on the balance, the lid only being removed immediately before closing the desiccator or oven. The fuel is again heated and weighed repeatedly until no difference is shown, and a calculation is made of the moisture from the initial and final weights as before.

During this test the temperature must not be allowed to rise above 180° F., regulation being made by the gas burner beneath.

It must be mentioned that there is a very strong probability that some of the lighter volatile matter will be liberated from the coal in the oven, so the result will not be scientifically accurate, but may be accepted as correct for all practical purposes.

Testing for Volatile Matter

The covered crucible, after determination of moisture, is placed on the iron tripod stand in a pipeclay triangle over a Bunsen burner, as shown in Fig. 5, the latter being kept low for a few minutes at first so as to avoid a too sudden evolution of gases blowing any of the powdered fuel out of the crucible. Smoke and gases will be seen to ignite as they issue from beneath the crucible lid, and the gas flame is gradually increased until the gases cease to be emitted.

The difference between initial and final weights will indicate the quantity of volatile matter contained in the coal, the weight of the crucible contents being the *coke* or residue of fixed carbon and ash. The volatile matter consists of various gases, spirit vapours and tar, which vaporise at a red heat.

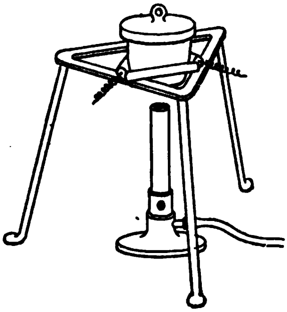


FIG. 5.—Crucible on Tripod.

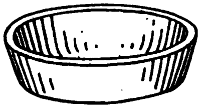


FIG. 6.—Silica Dish.

Careful note should be made of the nature of the coke left in the crucible, such points being observed as its hardness or otherwise, and whether coherent or with little tendency to cake, etc. This will furnish a very fair indication of the probable results of firing the coal in the actual furnace.

Testing for Fixed Carbon and Ash

A silica dish (Fig. 6), about 2 in. diameter and ½ in. deep, is taken and 5 grammes of the powdered fuel weighed into it.

The muffle furnace (Fig. 7) is lighted and the temperature raised to a bright red heat. The dish with the fuel sample is placed just inside the furnace at first and gradually pushed back as combustion proceeds, the contents of the dish being frequently stirred by means of a suitable "poker" (which may be made of a knitting needle set in a wooden handle), so that all portions will come into contact with the air and be perfectly consumed. In about an hour's time the process will be complete, and the resulting weight is the *ash* or incombustible residue. The percentage obtained from this figure subtracted from the percentage of coke gives the percentage of *fixed carbon* in the coal being tested.

Sulphur

The presence of sulphur in coal in any appreciable quantity is objectionable, as noted earlier in this chapter. Its estimation calls for considerable skill, and the services of a chemist should be utilised for this test. As the method of sulphur determination will no doubt be of interest, it is given here, as the subject of proximate analysis cannot be considered complete without its inclusion.

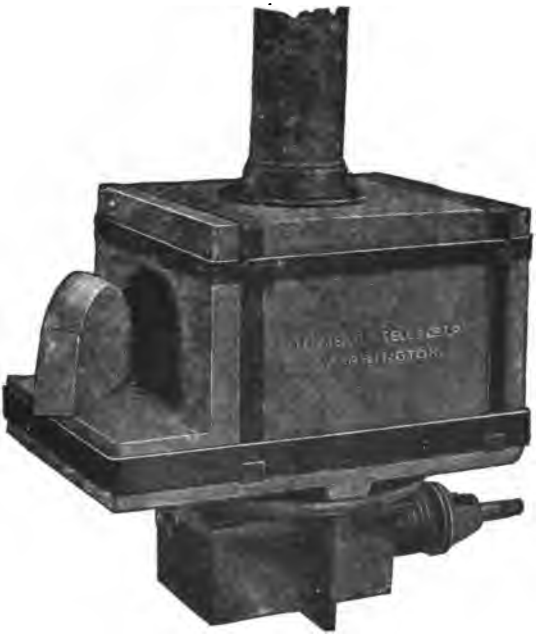


FIG. 7.—Muffle Furnace.

Mix 2 grammes of powdered coal with 2 grammes of pure magnesia and 1 gramme of sodium carbonate. Put mixture into a crucible and heat over a Bunsen burner until all the carbon is consumed. When cool, remove the resulting ash into a glass beaker and dissolve it in dilute hydrochloric acid. After filtering and washing, heat the filtrate (*i. e.* the liquid that has passed the filter paper) to boiling-point, and then add a solution of barium chloride in slight excess, which will precipitate the sulphur as barium sulphate. Boil the whole and then allow the precipitate to settle. Filter off the liquid, wash and dry the precipitate, and weigh the barium sulphate. As barium sulphate contains ·1373 times its weight of sulphur, the weight obtained above multiplied by ·1373 gives the quantity of sulphur in the original 2 grammes of coal.

Having obtained a "proximate analysis" of the coal we are able to classify it under one of the headings already described.

Calorific Value of Coal

The most important property of any fuel is the amount of heat that it is capable of producing when burnt. In purchasing coal, therefore, it must be borne in mind that, having a coal suitable in all other characteristics for the work it is required to perform, the determining factor as to its monetary value is the amount of heat it is possible to obtain from it.

The unit of heat used in this country is the *British Thermal Unit* (B.Th.U.), and is that amount of heat that will raise the temperature of a pound of water from 60° to 61° F.

The metric unit of heat is the *Calorie*, or that amount of heat that will raise 1 gramme of water from 0° C. to 1° C.

In this work the B.Th.U. will be adopted throughout, but the relation of this unit to the calorie is—

1 B.Th.U. = 252 calories.

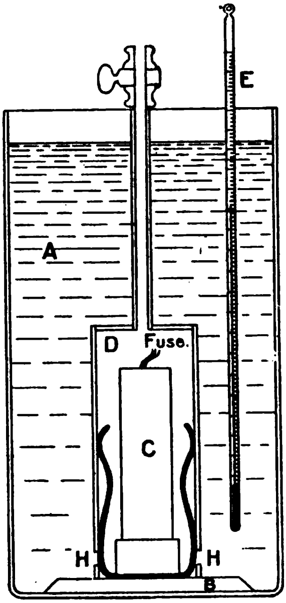


FIG. 8.—Lewis-Thompson Calorimeter.

When purchasing coal for steam-raising purposes it must be borne in mind that one is purchasing potential heat, and therefore it is only following the normal procedure in sale and purchase when investigations are made to ascertain the amount of heat that is being received for the expenditure.

The almost universal method of testing a coal for its calorific value or heat content is by some form of fuel calorimeter, which consists of a suitable arrangement for burning a known quantity of coal under a measured quantity of water, the calorific value being ascertained by calculation from the rise of temperature of the water measured upon a sensitive thermometer.

Four typical examples of calorimeter will be described, the principal variation in which consists in the method of obtaining the supply of oxygen necessary to ensure complete and rapid combustion.

The Lewis-Thompson Calorimeter is the simplest form of coal calorimeter in use, and is shown in section in Fig. 8, a complete outfit in case being illustrated in Fig. 9.

As for all forms of fuel tests, the sample is ground up finely so as to pass the 60-mesh sieve. Two grammes of this powdered coal are mixed with about twenty-four grammes of "oxygen mixture," which can be purchased ready made up, or prepared by mixing intimately three parts of potassium chlorate with one part of potassium nitrate (saltpetre), both ingredients being finely powdered. The fuel and oxygen mixture must be thoroughly mixed by rubbing together with a spatula or flat-bladed knife on a piece of glazed paper. When ready the mixture will be of a uniform grey colour.

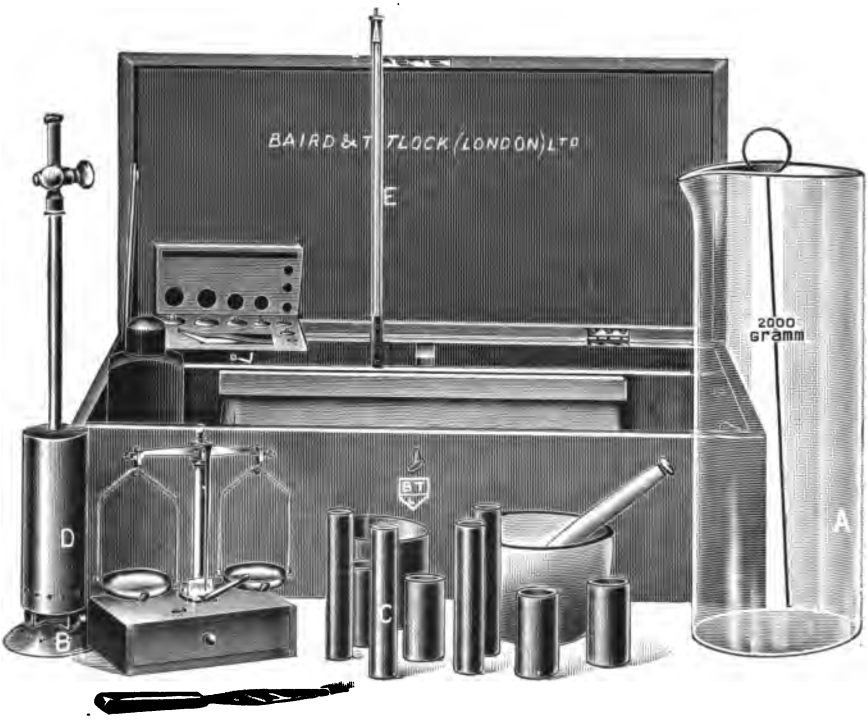

BAIRD & T TLOCK (LONDON) LTD
E
2000 Gramm
A
D
B
C
B T

FIG. 9.—Lewis-Thompson Calorimeter Outfit.

The glass vessel A is filled with 2000 c.c. of water, the temperature of which must be that shown in the following table corresponding to the temperature of the room—

Temp. of room	°F. 80	72	67	60	55	50	42
Water to be	°F. 70	64	60	54	50	46	40

Place the mixture of fuel, etc., in one of the copper cylinders (C), a little at a time, ramming down evenly each portion. Introduce a short piece of fuse with the last portion of fuel mixture; the fuse being made by soaking a length of cotton wick in a strong solution of oxygen mixture and drying. The cartridge is fitted into the socket in the base B, which is also provided with springs to hold the copper bell jar D in position. See that the relief cock on the pipe of the bell jar is closed.

Now take a very careful reading on the sensitive thermometer E, which is divided to $\frac{1}{10}°$ of a degree Centigrade.

Light the fuse, and immediately it begins to burn place the bell jar D on its base B, and lift the whole apparatus into the water in the glass jar A. In a few seconds active combustion, maintained by the evolution of oxygen from the heated mixture of chlorate and nitrate, will commence, the products being expelled in the form of a white smoke from the holes H in the bottom of D. The bubbles of gases agitate the water and maintain an even temperature. In a short space of time the bubbling will cease, and when this takes place open the relief cock and rapidly pass a steel wire down through the pipe to clear any obstruction. This will allow the water to rise in D. Rapidly raise and lower the whole apparatus, watching the thermometer carefully, and note when the reading is at its maximum.

It must be mentioned that in addition to the water in the glass jar, the metal instrument itself has absorbed some of the heat of combustion. All calorimeters have a capacity for heat absorption which has to be allowed for in the subsequent calculations, and this is usually stated as its "water equivalent"; that is to say, the corresponding quantity of water that would have to be added to contain the heat of the calorimeter.

In the Lewis-Thompson calorimeter this water equivalent is taken to be equal to an addition of one-tenth to the rise of temperature actually observed on the thermometer.

To calculate the calorific value of the coal from the test above described the following formula is used,

$$C = \frac{2000 \times (T + \frac{1}{10}T) \times 1{\cdot}8}{2}$$

where—

C = Calorific value in B.Th.U.
and T = Rise of temperature in °C.

C

As an example we may take—

Initial temperature of water		16 °C.
Final ,, ,, ,,		23·5 °C.
	Difference	6·5 °C.
	$+\frac{1}{10}$	·65
	Total rise	7·15 °C.

then—

$$C = \frac{2000 \times 7{\cdot}15 \times 1{\cdot}8}{2} = 13{,}870 \text{ B.Th.U.}$$

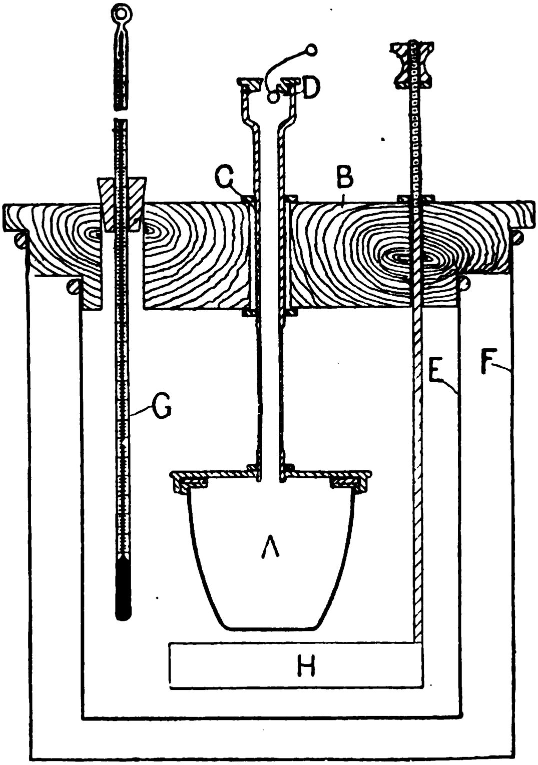


FIG. 10.—Roland Wild Calorimeter (A. Wright & Co., Ltd.).

Perhaps the best method of determining the water equivalent of a calorimeter is to test either a standard sample of coal or some other chemically pure substance of which the calorific value is known. For this purpose pure cane sugar is generally utilised, the calorific value of which is 7120 B.Th.U.

The Lewis-Thompson calorimeter cannot be considered as a scientifically accurate apparatus by any means, as it is very apt to give low results due to incomplete combustion, especially with "clinkery" coals. For rough comparative tests, however, it has its uses, and it certainly is used to a very wide extent, probably owing to its low cost.

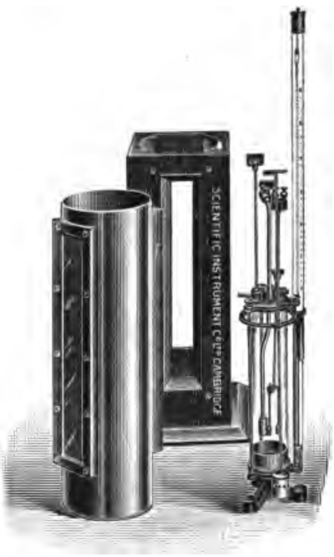


FIG. 11.—Rosenhain Calorimeter.

What is described by the makers (Messrs. Alex Wright & Co.) as a "low-pressure bomb" calorimeter is the "Roland-Wild" apparatus (Fig. 10). In this case sodium peroxide is used as the source of oxygen. The quantity of water used is 1000 c.c., less an amount corresponding to the water equivalent of the apparatus. This is placed in the containing vessel E, which is air-jacketed to minimise heat loss by radiation and provided with a wooden cover for the same purpose. The temperature of the water is regulated in the same way as for the Lewis-Thompson. Owing to additional heat being produced by the sodium peroxide a reduced quantity of powdered coal is used to compensate for this. The quantity of coal taken is 0·73 gramme and intimately mixed with about 13 grammes of sodium peroxide, this mixture being placed in the nickel "bomb" or crucible A. The crucible is screwed tightly into its cap, as shown; the thermometer G is fitted into the rubber stopper, with its bulb level with the bottom of A, so that the stirrer H does not foul it. Then place the cover B on the vessel. Take the temperature of the water after stirring. Heat a piece of nickel wire to a bright red heat and drop it immediately into the crucible through the valve D, drawing the ball into position by means of the wire which is attached to it. The charge being thus fired, the water is agitated by means of H, and a note made of the maximum temperature attained. As the water equivalent of the apparatus has already been allowed for, the calorific value of the fuel is—

$$\frac{1000 \times T}{\cdot 73} = 1370 \times T$$

where T = the rise of temperature in °F.

The next type of calorimeter to be considered is the Rosenhain

Fig. 11 (The Cambridge Scientific Instrument Co.), and in this instrument the supply of oxygen is obtained from an outside source. The pulverised coal is formed into a briquette, which is ignited by a platinum wire electrically heated, the combustion taking place in a stream of oxygen. The calorific value of the coal is calculated, as before, from the rise of temperature of the surrounding water, with corrections for water equivalent.

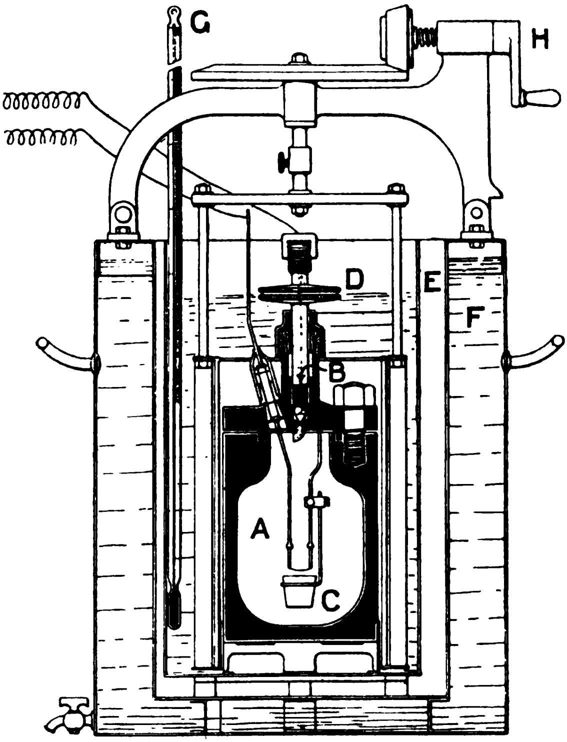


FIG. 12.—" Sarco " Mahler Bomb Calorimeter.

The receptacle for the sample under test in this case is a similar crucible.

The Darling Calorimeter is somewhat similar in action to the Rosenhain, the coal being placed loose in a platinum crucible and burnt in a current of oxygen. In both these last-mentioned types of calorimeter the bell jar is of glass, and the progress of combustion can be seen, which is necessary in a low-pressure oxygen calorimeter.

The calorimeter which is now accepted as a standard is the

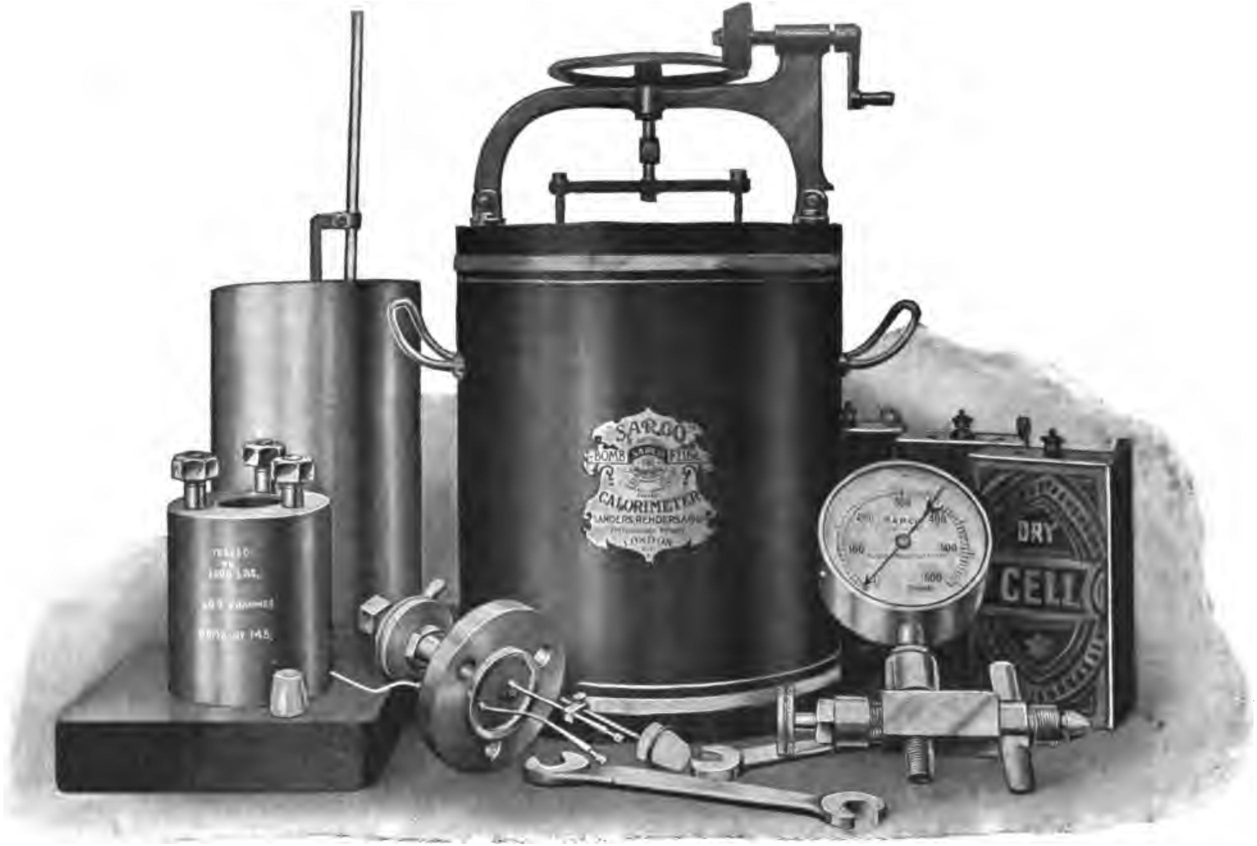


FIG. 13.— " Sarco " Calorimeter, showing constituent parts, etc.

Mahler-Donkin Bomb, which is supplied with various modifications by different makers, of which the "Sarco" pattern of Messrs. Sanders Rehders may be accepted as a good representative example. A section of this apparatus is shown in Fig. 12, and the various parts and accessories in Fig. 13.

The "bomb," or vessel in which combustion takes place (A), is of special non-corroding metal with high tensile strength; it is gold-plated inside, with a superimposed coating of platinum to ensure long life. The cover is fastened down by three studs and nuts, and jointed with lead wire. A screw-down needle valve B is provided to regulate the supply of compressed oxygen obtained from an ordinary cylinder. The crucible C, holding the sample of coal to be tested, is carried on a clip attached to one of the electrodes used for electrical connection to the platinum wire used for ignition, this electrode being in metallic connection with the cover of the bomb; the other electrode passes through an insulating bush.

The closed bomb is placed inside the inner vessel D, which contains a known weight of water. This vessel is surrounded by an air space E as an insulator, and a water jacket F to prevent errors due to variations in the outside temperature. The sensitive thermometer G is divided into fiftieths of a degree C.

When the bomb, containing 1 gramme of coal, is placed in the water the temperature is very carefully noted. The bomb is connected to the oxygen supply through the valve B, and is thus filled with oxygen under pressure. The coal is then ignited by passing an electric current from three dry cells through the platinum wire by way of the electrodes. Combustion takes place immediately, and the stirring paddles are kept rotating by means of the operating handle H. The maximum reading of the thermometer is noted, and the calorific value of the coal is obtained from the following formula—

$$(W_1 + W_2) \times T \times 1{\cdot}8 = \text{B.Th.U. per lb.}$$

where—

W_1 = Weight of water in vessel D.
W_2 = Water equivalent of apparatus.
T = Rise of temperature in °C.

A method of obtaining the water equivalent by calibrating with pure cane sugar has been given, but this figure is usually supplied by the manufacturers with each instrument.

Other bomb calorimeters are the Berthelot and Hempel.

A low-pressure calorimeter, giving very accurate results, is the Fischer, which consumes the coal sample in a platinum vessel in a stream of oxygen. Its low price is a recommendation, but for accurate and reliable results the Mahler bomb is pre-eminent and should be utilised wherever possible. Modifications of the Mahler Calorimeter are supplied by Messrs. Baird & Tatlock (original form) and by Messrs. Gallenkamp.

Importance of Coal Tests

The value of the tests described in this chapter, as an indication of the quality and heat value of the fuel supplied, cannot very well be over-estimated. In this country the purchase of coal by calorific value has not been adopted to more than a very small extent, owing mainly to the objections made by the suppliers of the coal, who will not guarantee any particular calorific value, although they may supply an approximate (usually high) figure when tendering for contracts. If, on the other hand, the industrial consumers of coal could make a combined stand in this matter, perhaps it would compel the contractors to admit the fairness of the principle of purchase by calorific value.

At present it is the practice to submit samples of the coals offered on a contract, but no undertaking is entered into to supply coal to this sample governed by analysis and calorific value tests. As a consequence, if the consumer finds his coal deteriorating from the quality originally supplied, his only course is to make a complaint to the contractor, with an intimation that if no improvement is observed it will prejudice his chance of renewing the contract at the termination of the existing one.

A little reflection will show that merely accepting the coal and paying for it by the weight received is a system that would not be tolerated in any other form of business, for in buying coal it is *heat* that is required and not weight of material which varies considerably within sometimes very short periods.

Of course, in arranging a contract for supply of coal on the calorific basis, a reasonable allowance should be made for variation, and the particular figure quoted should be an average during reasonable periods of time, say monthly or quarterly.

It must also be borne in mind that the *evaporative* value of the coal does not vary proportionately with the *calorific* value, actual tests under boilers revealing the fact that as a general rule the poorer coals give an inferior result as regards efficiency than the coals of higher calorific value; that is to say, the efficiency curve is steeper than the heat value curve. This is due to the fact that most shales (the usual impurity in coal) have a measurable calorific value, which is quite unavailable for steam-raising purposes, owing to the impossibility of maintaining such high temperatures of combustion in actual working conditions as are found in a calorimeter.

As coal varies in analysis and heat value very considerably, even from the same workings of one colliery, tests should be taken at regular and frequent intervals and entered either in a book or, better still, a card-index. If any serious variation is observed, a test under working conditions should be made to see if the same evaporation is obtained, and the same cost of evaporating 1000 galls. of water. This test should also be one of the determining factors in deciding the placing of a coal contract in the first instance.

The records of tests should comprise the following details—

Name of Colliery—
Class of coal—
Date delivered—
Wagon No—

Description of coal—
  Percentage large; percentage small; percentage slack.
  Calorific value—
  Percentage :—Moisture, Volatile, Fixed Carbon, Ash, Sulphur.
    Notes on nature and appearance of Coke and Ash.
    Weather conditions between dates of dispatch and delivery.

Result of working test—
  Price per ton—
  Tested on Boiler No—
  Hours run since flues cleaned—
  ,, ,, ,, boiler scaled—
  Water evaporated from and at 212° F.—
  Thermal Efficiency percentage.—
  Percentage ash—
  Cost of evaporating 1000 galls. of water—

TABLE I.

CALORIFIC VALUES OF BRITISH COALS.

District.	Class of Coal.	Calorific Value, B.Th.U.		
		Max.	Min.	Average.
S. Wales . .	Anthracite	15,600	15,100	15,400
,, . .	Semi-Anthracite	15,000	14,500	14,750
,, . .	Semi-Bituminous	15,000	13,500	14,200
,, . .	Bituminous	14,900	13,500	14,100
Durham .	,,	14,400	13,300	13,700
Gloucester .	,,	14,400	13,500	14,100
Lancashire .	,,	13,700	13,200	13,400
Leicester .	,,	14,000	12,500	13,200
Northumberland	,,	14,000	13,000	13,500
Nottingham .	,,	14,000	12,000	13,100
Staffordshire .	,,	14,400	12,200	13,400
Warwickshire .	,,	13,000	11,300	12,100
Yorkshire .	,,	14,800	12,600	14,300
Scotland . .	,,	14,000	12,000	13,200
,, . .	Semi-Bituminous	14,500	13,500	14,000
,, . .	Semi-Anthracite	15,000	14,500	14,750

CHAPTER III

COMBUSTION OF COAL.—Outline of chemistry of combustion and what takes place in burning of coal—Heat—Boiler and furnace firing-methods, with advantages and disadvantages—Ideal conditions of firing boilers.

BEFORE it is possible to obtain a clear idea of the various changes which take place when burning coal in a furnace, some general knowledge of the fundamental chemical principles governing these phenomena is absolutely essential.

It is first necessary to have an understanding of certain elementary chemical facts.

Chemists class all matter under three distinct heads, viz.—

I. Elementary Substances or *Elements.*
II. Mechanical Mixtures.
III. Chemical Compounds.

I. ELEMENTS

Elements are those substances which cannot be split up into simpler bodies.

The elements consist of substances which include solids, liquids and gases at normal temperatures. Each element is known in chemistry by a symbol, in most cases the initial letter of the Latin name. The elements which interest the reader of this work are—

Carbon, symbol	C.	Nitrogen, symbol	N.
Oxygen, ,,	O.	Iron, ,,	Fe.
Hydrogen, ,,	H.	Sulphur, ,,	S.

II. MIXTURES

A *mixture* is two or more elements or compounds in intimate contact but still preserving the individual characteristics of its components, and which may be separated into its constituent parts without recourse to laboratory methods. Chemists indicate mixtures by a *plus* sign between the symbols of the elements or formulæ of the compounds composing it, thus—

$S + Fe$ indicates a mixture of sulphur and iron; or
$CO + H$ indicates a mixture of carbon monoxide and hydrogen.

III. COMPOUNDS

Compounds are formed of two or more elements chemically combined, the resulting substance having distinctive properties of its own. The elements constituting the compound have a small figure attached to them when more than one proportion are contained in the compound, thus—

CO (carbon monoxide) is a colourless, poisonous, inflammable gas composed of one part of the black solid carbon and one part of the colourless gas oxygen, both of which individually are non-poisonous.

CO_2 (carbon dioxide) is a colourless, non-poisonous, heavy gas in which the oxygen is only one proportional part more than in CO, yet the gas has quite different properties and is non-inflammable.

Chemical action is said to take place when the various elements combine or decompose with the evolution of heat. *Combustion* is said to take place when chemical action takes place with the evolution of light and flame as well as heat.

A few substances ignite at ordinary temperatures.

The substances we have under consideration only ignite considerably above atmospheric temperature, and therefore require an external source of heat to initiate the action, which, when once commenced, produces sufficient heat of itself to maintain the temperature at ignition point.

Oxidation or rusting of iron is an example of slow combustion, the evolution of heat being spread over such a protracted period that the rise of temperature resulting is too small to be detected.

Before describing the general principles of the chemistry of coal combustion, the author wishes to note that the sequence of events set out later are not chemically accurate, the reactions involved being very intricate, and even at the present day are a matter of discussion among investigators.

Nevertheless, if not scientifically correct, the following explanation of the process of combustion may be accepted as representing what takes place in the furnace sufficiently accurately for all practical purposes, and a reliable guide for the engineer who wishes to obtain the best results from his coal.

When coal is thrown upon a clear fire the volatile matter is the first to be expelled. This volatile matter consists of various gases, liquids and solids. They all belong to the very large class of compounds known in chemistry as *hydrocarbons*. These hydrocarbons, as their name suggests, consist of the two elements carbon (C) and hydrogen (H), combined in greatly varying proportions such as—

Methane,	formula	CH_4
Ethylene,	,,	C_2H_4
Acetylene,	,,	C_2H_2
Benzene,	,,	C_6H_6

and innumerable others.

On application of sufficient heat they are finally broken up into their constituent elements C and H. The carbon vapour (C) combines with the oxygen (O) in the atmosphere to form firstly

CO or Carbon Monoxide,

which in burning takes up more O and becomes

CO_2 or Carbon Dioxide.

The hydrogen (H) burns immediately to H_2O or water vapour. So that if combustion is complete after burning in just the correct quantity of air, all that will remain is CO_2, H_2O and nitrogen (N), this latter gas forming four-fifths of the atmosphere but is quite inert chemically and only acts as a diluent.

Dealing now with the "fixed carbon," which, together with ash (incombustible residue), forms coke; when it is heated to ignition point it passes through the same stages of CO and CO_2 as the carbon vapour of the volatile matter, leaving a residue of incombustible ash composed of silica, alumina and other impurities from clay, shale and earthy matter.

Thus we see that with the air supply correctly proportioned the ultimate result in the flue gases will be CO_2, H_2O vapour and nitrogen.

The small proportion of sulphur burns to SO_2 and SO_3 (sulphur dioxide and trioxide respectively), forming with the H_2O vapour H_2SO_3 and H_2SO_4 (sulphurous and sulphuric acids).

In actual practice it is quite impossible to obtain the perfect combustion of the fuel as outlined above owing to the difficulty of accurate regulation of the air supply.

HEAT

Every chemical reaction is accompanied by the evolution of a definite amount of heat. All fuels used for furnace work in any form are substances which contain the necessary constituents, which more or less readily combine with atmospheric oxygen, and thus furnish the reaction by which the required heat is evolved.

Heat is a physical state in a substance, either transferred from another source or produced in it by absorption of energy of mechanical work or the passage of an electric current. Heat as such cannot be transmitted through a vacuum, but must have some liquid, gaseous or solid body to conduct it. Those bodies which conduct heat most readily are the metals, particularly copper, whereas such materials as cork, wood, magnesia, still air, water, etc., are very poor conductors of heat, and those which are the worst conductors are termed heat insulators. The fact that heat cannot pass a vacuum is demonstrated in the vacuum flasks so widely used for keeping liquids hot or cold for very long periods.

Radiant heat, as it is termed, is capable of conduction through a vacuum, as exemplified in electric incandescent lamps, or even the heat of the sun. Its properties are very similar to that of light, as it passes through glass without hindrance, but is screened by opaque bodies which absorb it and rise in temperature. The theory of radiant heat is that the heat energy first forms light, which is transmitted in the usual way, and is again converted into heat on contact with an opaque body. This is of the greatest importance to bear in mind in connection with the transmission of heat from boiler furnaces to the heating surfaces, as will be seen later.

The engineer responsible for fuel consumption should train himself to think in terms of heat. Heat is bought in purchasing the coal, and every particle of this heat should be efficiently utilised, and wherever it escapes, either as steam or in waste gases, friction or radiation, it is so much of the original material irretrievably lost. It is of interest to the fireman and ash wheeler, as less coal burnt is less physical strain.

In firing furnaces by hand there are three methods practicable.

1. *The Spreading Method.*—This consists of throwing evenly distributed charges of coal on to the fire at intervals, and when boilers are being worked to their maximum capacity in conjunction with an ample air supply, easily regulated, very good results may be obtained, provided that the fireman is a skilled hand. Under easy working conditions this method should never be used, as the volume of cold air admitted when opening furnace doors is, of course, much greater in proportion to a smaller fire than a heavy one, due to the absorption of heat by the air in raising it to furnace temperature.

2. *The Coking Method.*—In this system of firing fresh coal is not fed direct on to the fire bed. In firing each fresh charge the "green" coal is placed on the dead plate at the furnace door after the previous charge has been pushed back over the fire with a rake. The gases are distilled from the fresh fuel and are heated by the incandescent bed of coke on the grate, and finally consumed by the excess of air which passes through the coke and is heated in so doing. The indraught at the open doors is considerably diminished also by the greater thickness of the fire adjacent to the fire-door. Forced draught is advisable to get the best evaporation by coking firing by hand.

3. *Side Firing.*—This is practically a combination of methods 1 and 2, and consists of firing successive charges of coal alternately on one side of the grate and the other. A greater evaporation of water is obtained by this style of firing than by coking.

For firing slack coals by hand the spreading method of firing is the only practical way, but as the use of slacks for firing necessitates small charges at a time, so as to avoid "blanketing" the fire and preventing the admission of air, the fire-door has to be opened so frequently for the purpose that this class of coal cannot possibly give a good efficiency when fired by hand, and should be used only for mechanical firing.

The highest efficiency is obtained by the coking method, but the highest evaporation cannot be obtained thus, and where additional boilers cannot be installed, or other aids to increased capacity adopted, it is frequently impossible to adopt entirely. Where the steam demand is steady the plant should be laid down of sufficient capacity to permit of this method, and where there are varying intervals of heavy and light demand, coking should be used during the easy intervals when these are of sufficient duration.

In most cases where the spreading method is used it will be found that side firing can be adopted to meet all demands and with greatly improved results in efficiency.

CLEANING OF FIRES

Fires should not be allowed to burn down too far before cleaning clinker and ash from the grate, but this must be done with about three inches of burning fuel left on the bars. This fuel is pushed all to one side of the grate, and the clinker and ashes sliced and raked out. The unburnt fuel is then transferred to the cleaned side of the grate, so that the remaining clinker, etc., is removed. Place the fresh charge of coal on the clean bars of the side last cleaned, and continue side firing as described.

While fires are being cleaned the dampers must be lowered sufficiently, so that there is only enough draught to carry away the gases without an undue inrush of air. If this indraught of air is permitted it cools the boiler and furnace, carrying a bulk of the heat contained in the boiler away to the outlet flues, which heat is lost.

Also when boilers are working into a common flue, an unrestricted rush of air through one boiler in the group will seriously reduce the air supply to the remainder, resulting in incomplete combustion and consequent heat loss.

The ideal conditions to be aimed at in firing boilers are to obtain as intimate a mixture of fuel and air as will lead to rapid ignition and combustion; also to attain complete combustion, with maximum temperature of the gases, as close to the furnace as possible. The air supply must be constantly and carefully regulated, so that no excess or deficiency arises and perfect combustion is maintained. Ignition of the fuel must be immediate and complete, and the size and quantity of coal regulated to secure this end.

The air space between the fire-bars must be kept clear at all times by use of the slice-bar, so that accumulations of clinker and ash are broken up. The slice-bar must not be used to prise up the underlying mass of clinker into the coal above, but the point of the bar should be pushed along the surface of the grate, merely easing the clinker off the bars and breaking it up. If this is not carefully done, coal and coke will become mixed with the molten slag, and it will be then impossible to burn it thoroughly.

Immediately after, and for a short time following a fresh charge of coal, the air supply through the bars is insufficient to burn the large volume of gases emitted, and it is essential that the supply of air over the furnace through the doors should be continued until all tendency to smoke is gone; the air shutters are gradually closed till this secondary air supply is no longer needed.

Banking Boilers.—When boilers are not required for a short period it is usual to " bank " the fires, that is to say, a sufficient quantity of coal is left on the fire-bars to maintain a reduced pressure of steam until the boiler is required again. This should only be done when the interval of rest is comparatively short—not more than twenty-four hours—unless it is necessary to have a stand-by boiler at hand to meet sudden and unexpected demands. As the latter contingency also requires the presence of the necessary labour to deal with it, it would be more economical to work this boiler under part of the load carried otherwise by the remainder, as the lighter a boiler is worked, within limits, the greater is the efficiency obtained. That is to say, if two boilers are carrying a fairly heavy load and a third is banked as a stand-by, in all probability it would be better as regards fuel economy to work all three boilers together at two-thirds each of the load originally carried on each of the two boilers at work.

This is limited, of course, by the thickness of fire carried, and sufficient demand of steam must be present to require reasonable fire thickness, or otherwise excess air and bare patches of grate will be the result.

The correct method of banking fires is to keep a good pile of glowing coal on the front of the fire-grate, leaving the back end bare, and then lower the dampers so that just sufficient air is admitted to permit of slow combustion and maintenance of the required reduced pressure. Theoretically, only sufficient heat should be produced to compensate for loss by radiation, but in practice it will be considerably more.

Where boilers which have sliding pattern dampers have to be banked, a hole about one and a half inches diameter should be drilled near the top of each damper so as to release any accumulation of carbon monoxide or hydrocarbon gases and air, which may lead to explosions in the flues.

Explosions in Furnaces.—When firing bituminous coal either on boiler or steel-heating furnaces, care must be taken that there is sufficient draught to carry away the hydrocarbon gases rapidly, for on application of the draught (especially forced draught), serious explosions may occur owing to the sudden influx of air providing an explosive mixture. Explosions do not, as a rule, occur except when firing too heavily; but if this very uneconomical practice is resorted to, explosions of more or less degree may, and *do*, often result.

The disadvantages of slack coals for hand firing have already been referred to. Large coals *must* be broken up before use, as by placing large lumps of coal upon the bars the air supply is blocked and the grate area reduced, whereas there is an enormous generation of gas from these masses of coal which cannot possibly be dealt with by the reduced air supply available. As a consequence, volumes of smoke are emitted, representing an enormous waste of coal, together with injury to health and property, and also serious reduction in the boiler and economiser capacities due to the heavy deposits of soot upon the surfaces of plates and tubes.

Firing too thinly and unevenly leads to an excess of air, with corresponding loss of heat, with bare patches of grate, which pass all the air supply, or most of it, leaving the remaining fuel unburnt. Firing in too large-sized lumps also leads to holes in the fire, with the same results.

In applying the foregoing remarks to the firing of steel furnaces, the references to sizes of coal, firing and cleaning methods are equally applicable. Also, as regards using too large sizes of coal where waste heat boilers are installed, this practice, in addition to the emission of smoke, considerably lessens the output of steam, and thus largely defeats the purpose for which the boilers are installed.

In furnace firing, the regulation of the working temperature is, of course, the most important factor, which ranges over the comparatively low heats required for treatment furnaces, to the melting heats used in puddling furnaces. The regulation of temperature should be made by varying the thickness of the fire, together with corresponding adjustment of the air supply. In some cases, where the grate area is too large to allow a sufficiently thick fire and efficient combustion without excess temperature, it leaves no option but to pile on a heavy charge of coal to blanket the fire, as by leaving the fire too thin for the same purpose it leads to oxidation and excessive scaling of the steel or iron. This in some measure may account for the smokiness of furnace chimneys, which seems to be accepted as inevitable, although, in the author's opinion, there is no more need for black smoke from a furnace chimney than from a boiler plant. There is a saying (and a very true one) that "Where there is smoke there is money," but surely the right place for money to be found is not at the top of a chimney and being wasted in thin air!

There is no doubt that with improved design of furnaces and more intelligent firing the smoke at present disfiguring our large industrial towns will be mostly, if not entirely, abolished, with satisfactory results both in health and pocket to all concerned.

CHAPTER IV

Furnaces.—Fire-grates and hand-fired furnace construction—Fire-bars—Fire-bridges—Secondary air supply—Refractory linings—Typical mechanical stokers, with notes on practical operation.

In considering fire-grates it must be borne in mind that the object of the grate is to support the fuel whilst burning, and in doing so to provide for an ample supply of air between the bars so that the combustion is not unnecessarily impeded. This leads to the logical deduction that the best fire-grate is that which has the largest air space or effective grate area consistent with reasonable mechanical stability. The fire-grate area is usually described in measurements obtained by the product of length and width. This figure alone, without any reference to the space between the bars, gives little idea as to the relation between the effective grate area and heating surface of a boiler. The limit of effective area in proportion to the total area is obtained in practice in fire-bars ½ in. in thickness with ½ in. spaces between adjacent bars. After deducting the thickness of metal, area of bearer bars and distance pieces, it will be found that the effective area of fire-bars of the dimensions given is somewhere about 40 %, so that with a fire-grate 6 ft. long by 3 ft. 6 in. wide, fitted with bars of the type shown in Fig. 14, the total area will be 21 sq. ft., with an effective area of 8·4 sq. ft. Fire-bars should be designed with a deep "fish-belly," so that a maximum surface is offered to the cooling effect of the air, in order to reduce the risks of burning the bars. Another factor which has considerable bearing upon the longevity of fire-bars is the material from which they are manufactured, the very best for the purpose being the commonest iron cast from the poorest quality scrap iron. The higher grades of hemitite irons fuse very readily, besides being expensive.

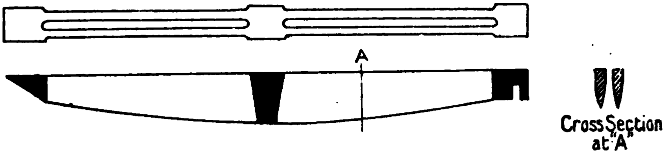


Fig. 14.—Double ½ in. × ½ in. Fire-bar.

Where small coals are used, a much reduced air space between fire-bars is necessary in order to prevent coal falling through; and it is usually necessary to provide forced draught in these cases to overcome the resistance offered by the restricted air passages and ensure proper combustion.

Fire-bridges in cylindrical boilers are only provided as a guard to stop any coal from being thrown over the back of the grate into the furnace flue. Eight inches height above the grate level is ample. Any higher bridge will unduly restrict the draught and lead to smoky fires. As 6 in. is the maximum thickness for a fire (under normal draught conditions), to give highest efficiency the height of bridge given allows plenty of margin.

As generally supplied, Lancashire boilers are provided with a fire-grate 6 ft. long, varying in width with the flue diameter, which in itself is not the same with all makers in boilers of similar outside dimensions.

With good fires on the front of the grate it is quite impossible to judge what conditions exist at the back end, which may be wholly or partly uncovered. To obtain the best results a 5 ft. 6 in. grate is the longest consistent with a sufficient ratio of heating surface to grate area.

The efficiency of a boiler depends very largely upon the ratio of heating surface to grate area, and, compared with high-efficiency tubular boilers, the heating surface of a Lancashire is very deficient. Whereas a water-tube boiler may have a ratio of heating surface to grate area as 50 : 1, that of a Lancashire with 6 ft. grates will be about 25 : 1, or only half the heat-absorbing capacity.

These 6 ft. grates were designed for districts and times in which coal was not appreciated at the value which is recognised (and paid for) to-day, the only consideration being the capacity of the plant installed to meet the demands made upon it.

A 30 ft. × 9 ft. Lancashire boiler will have a total grate area of 44 sq. ft., with 1,100 sq. ft. heating surface; the ratio is 25 : 1. In reducing the grate area by shortening the grates to 5 ft. the ratio of 30 : 1 will be obtained, with corresponding increase of efficiency and better combustion due to improved draught through the bars. Even under these conditions a Lancashire boiler cannot be expected to compete in efficiency with tubular boilers, without the additional assistance of an economiser, which virtually amounts to a corresponding increase of heating surface.

Another essential to complete combustion is an ample space over the back end of the fire-grate. Again in this respect Lancashire and similar furnaces are deficient, the combustion space being restricted by the walls of the furnace and flue tubes. The grates should slope not less than 4 in. from front to back to give the greatest combustion space possible.

Summarising, we may state that forcing boilers or using too large a grate area in proportion to the heating-surface is most uneconomical, and that a good margin of boiler power should always be provided to meet the demands for steam.

The provision for the secondary air supply for burning the volatile matter readily, requires particular attention. The firing-doors of all hand-fired boilers, with natural or induced draught, should be provided with a shutter, at a little distance (about 2 in.) from which on the fire side is fixed a perforated cast-iron plate, the perforations in which split up the air into numerous fine streams which mix with the gases and cause complete ignition and combustion. If this air can be heated before admission to the furnace, greatly improved results will be obtained. The use of " split " fire-bridges is not recommended, as the rush of cold air through the bridge into the flue tube will cause unequal stresses in the plates, with possibly leaky seams and internal grooving as a result. Also when the total draught available is not more than that necessary for burning the fuel on the bars, a split bridge defeats its own ends by robbing the grate of air and causing additional smoke, so that there is little or no improvement. A supply of air through the door-grid is more readily regulated, and does not take its supply by way of the ash-pit opening as does a split bridge, and therefore will in all probability not reduce the fire-grate air to so large a degree.

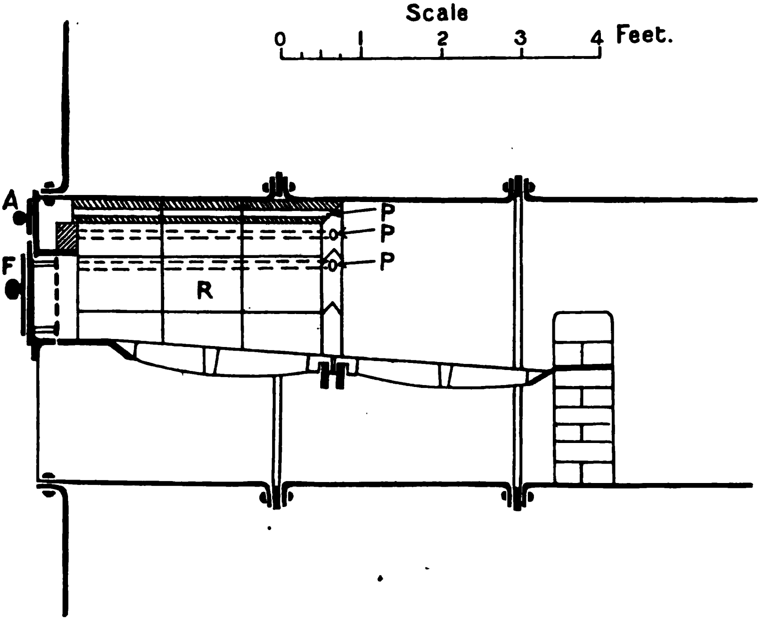


FIG. 15.—Suggested Design for Lancashire Boiler Furnace.

Recourse to opening of fire-doors to prevent smoke after firing should be avoided. It is impossible to make large volumes of air and gas at different temperatures mix properly, and, as a consequence, if smoke has to be prevented by opening the doors, a great excess of air has to be admitted, with considerable loss of heat thereby.

Additional suggestions that will improve the efficiency of hand-fired furnaces are—

Firstly.—A means should be provided so that the bars may be sliced without the necessity of opening doors to do this. A hinged flap covering an opening of sufficient size to admit the slice bar at the bottom of the door would meet this requirement.

Secondly.—The fire-box should be provided with a semicircular lining of fire-brick 3 in. thick, extending 3 ft. into the furnace, this lining being perforated longitudinally with 1 in. holes, connected with openings in the fire-box front for admission of secondary air, which thus becomes pre-heated before use. The refractory lining serves the purpose of an ignition arch, as it stores a large amount of the heat of the fire and remains incandescent when firing fresh coal, thus ensuring immediate ignition.

Fig. 15 shows a section and front elevation of a fire-box embodying the author's suggestions, and which will be found to meet all the requirements for the most rapid, complete and early combustion.

Mechanical Stokers

As already pointed out, small coals cannot be fired by hand with efficient results owing to the necessity for continuous feed of small quantities of coal. In hand-firing this would require the continual opening of the fire-doors, with accompanying losses due to influx of cold air.

Mechanical stokers are designed primarily for the economical use of coals, from nuts down to fine slack, with which they can be worked at a very high efficiency.

There are two general classes of mechanical stokers, viz.—

I. Sprinkling Stokers,
II. Coking Stokers,

Class II being the larger.

Class I.—Sprinkling Stokers

These stokers approximate closely to the spreading method of hand-firing, the most widely used being the Bennis and the Proctor. Their use for water-tube boilers is now practically discarded; but they are very largely used for firing Lancashire, marine and other boilers with internal furnace tubes.

The Bennis Stoker is a good representative type of the class. The stoker is operated from a rotating shaft through a reducing gear-box and slowly revolving shaft, upon which are mounted on the right-hand side of the hopper the adjustable feed cam, and on the left-hand side the throwing cam. The two sides are illustrated in Fig. 16 (R.H.) and Fig. 17 (L.H.). The feed cam operates a feed plate under the hopper, which allows a small quantity of coal to fall in front of the shovel four times per revolution of the shaft, this feed occurring alternately with the throw of the shovel. The feed cam can be adjusted by the hand nut on the shaft, which nut either closes or allows to open the two sides of the cam, thus giving a shorter or longer travel to the feed plate by the bell-crank lever.

The throwing cam (seen in Fig. 17) has four arms of different length. Each arm of the cam draws back the shovel, and in doing so compresses the spring in the pneumatic dashpot and suddenly releases the shovel arm again, which is forcibly thrown forward by the action of the spring; in doing this a charge of coal about eighteen inches long is delivered on the gate. The position of each charge varies with the length of the throwing cam arms, the coal being spread in four different zones with each revolution of the cam shaft. In the intervals between each delivery of coal there is sufficient time for each charge to become incandescent. It will be seen that the action is a combination of the spreading and side-firing methods, only differing from the latter in that the grate is divided into four sections instead of two, and that it is divided in length instead of width. As this stoker is designed for using fine slacks, close bars with forced draught (provided by steam jets) is supplied. The fire-grate (Fig. 18) is made up of hollow troughs sloping to the back of the furnace in which are fitted short longitudinal

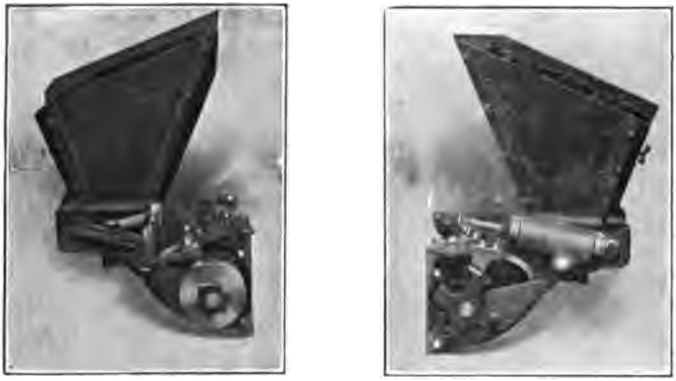


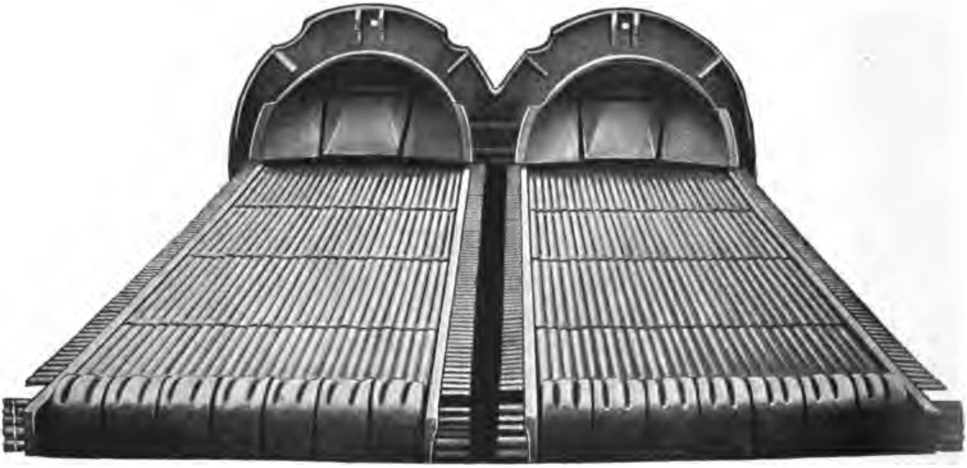
FIG. 16. FIG. 17.

Bennis Stoker.

fire-bars. These trough-bars are provided with bell mouths at the front of the stoker, into which air is injected under pressure by superheated steam. Each of these troughs is worked backwards and forwards by a cam-shaft, independently of each other, this causing the fuel to be worked back down the grate, and the remaining ash is discharged over the back of the grate.

As with every other type of mechanism, certain details require attention in order to get the best results.

Before lighting up the fires the stoker should be worked a couple of revolutions with coal in the hopper and then stopped, and the grate then examined to see that it has received a layer of coal all over. If the throwing cam is worn, the back of the grate will not receive its share of coal, and as the longest arm of the cam will wear most rapidly, the coal will tend to heap up before reaching the end of the grate. The throw of the shovel can be increased by tightening the tension nut at the end of the spring cylinder nearest the boiler front, and decreased by slackening.



Ed. Bennis & Co., Ltd.

Fig. 18.—Bennis Stoker Fire-grates.

The steam jet nozzles must be quite central with the front openings of the trough bars, and also must be renewed when showing signs of becoming enlarged or distorted.

The steam for the jets is superheated by carrying the supply pipe for a short distance along the boiler side flue, and the greatest care must be taken to see there is no leakage in this pipe, as it may seriously score the shell of the boiler by the sand-blasting action set up in conjunction with the suspended flue dust.

As observation of the fires is very difficult in this form of stoker, a periodical trial without fires as already described must be carried out so as to check the operation. Tests of flue gases will usually indicate any irregularities in this direction.

Class II.—Coking Stokers

All the types of stokers which are described in the following pages work practically upon the coking principle.

A well-known type of coking stoker for cylindrical boilers with internal flue tubes is the "Koker" of Messrs. Meldrum, Bros. As shown in Fig. 19, the essential portions of the operating mechanism is a sector-shaped ram, which in oscillating feeds the coal on to the front of the fire-grate as it is supplied to it from the hopper above. This ram has means of adjustment of throw, and the grate is provided with a very similar arrangement of fire bars to that of the Bennis Stoker, operated by a cam-shaft and having provision for forced draught. It works well with a good natural draught, but forced draught is advisable.

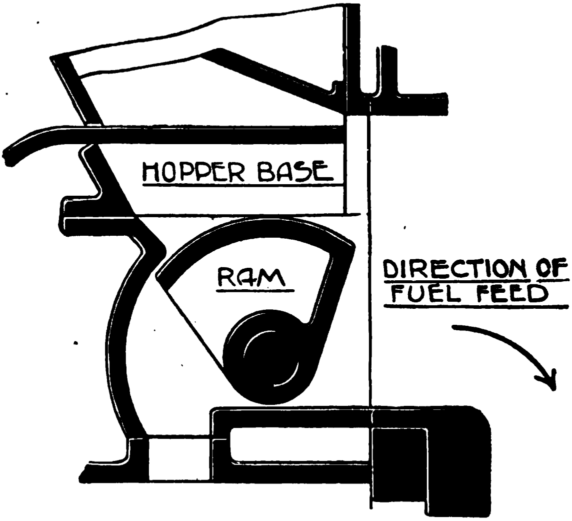


FIG. 19.—"Koker" Stoker.

The "Underfeed" stoker is supplied in two forms, differing mainly in the method of feed. The type used in Lancashire boilers is shown in a longitudinal section in Fig. 20 and in cross-section in Fig. 21. The coal is fed from a hopper on to the archimedean screw, which in revolving causes the fuel to travel along the trough or retort towards the back of the furnace. The coal gradually overflows from the retort out on to the fire-bars, which are stepped down to the flue-walls, and finally reaches the sides in a completely burnt condition. The volatile portion of the fuel is distilled off in the retort by the heat of the incandescent fuel above, through which it passes and is burnt, the remaining coke being burnt on the fire-bars by the forced draught of air supplied.

In the larger area of grates fitted under water-tube boilers the type of stoker shown in Figs. 22 and 23 is used. The coal is fed into the trough by a steam-operated reciprocating ram. This ram is connected to the sliding bottom of the trough or retort, and the two move together. Fixed in the sliding bottom are three sets of coal raisers, which serve to feed the coal on the forward stroke and lift it upwards on the return stroke. The action up to this point resembles that of the screw type of stoker already described, the distillation of the gases and burning of these and the coke being carried out in precisely the same

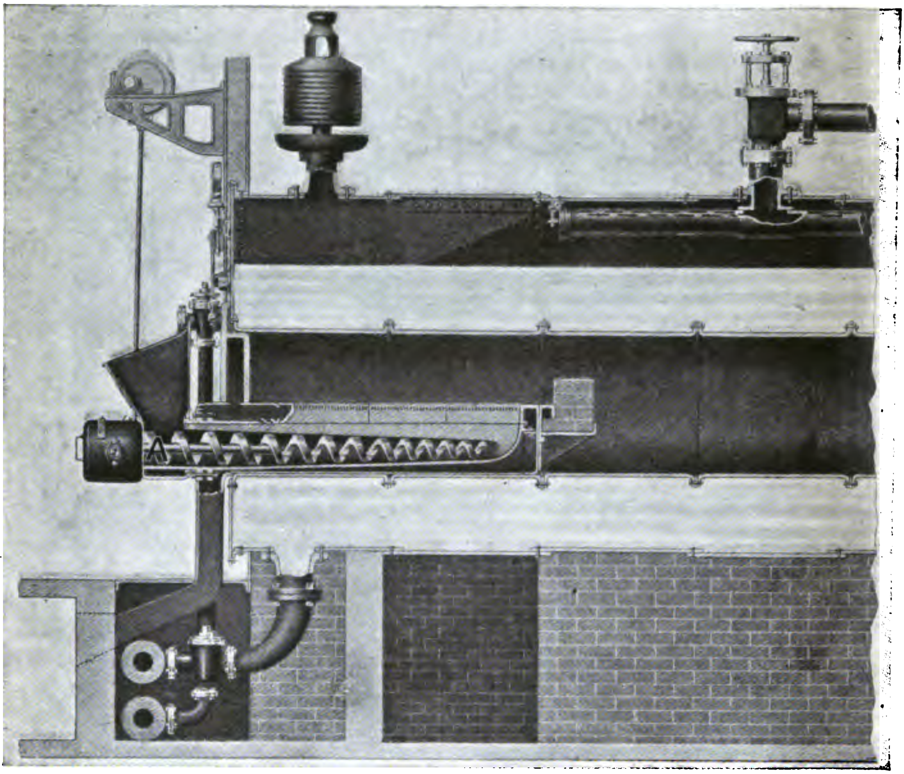


FIG. 20.—" Underfeed " Stoker, Screw Type (longitudinal section).

way. Owing to the greater width of grate, however, gravity cannot be utilised to any extent to cover the fire-bars, so these latter are arranged transversely and are fitted in alternate pairs of fixed and moving bars, thus working the coke down the sides of the grate until the spent ash is delivered on to the dumping doors at each side of the furnace.

The forced air draught is first delivered into the air trunk immediately beneath the sliding bottom of the coal trough, and thence passes into the centre ends of the hollow fire-bars; passing down these, the air becomes heated and cools the bars to a corresponding extent; after leaving the bottom ends of the bars, it finds its way through the enclosed hot air box, and makes a final exit between the bars through the fire-bed above.

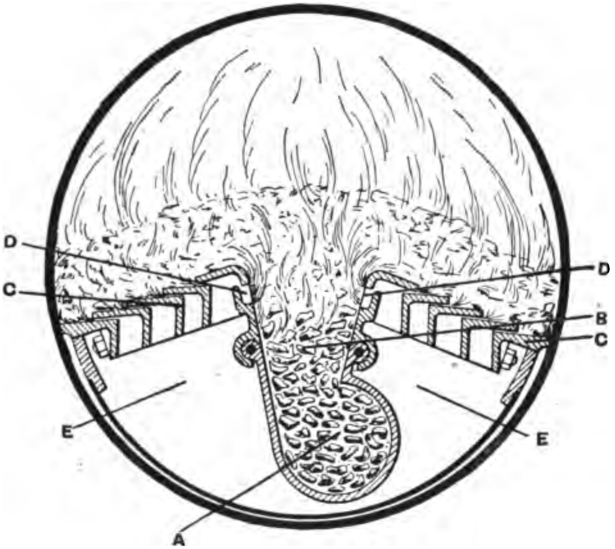


FIG. 21.—" Underfeed " Stoker, Screw Type (cross-sectional elevation).

In both types of "Underfeed" stoker the forced draught should be so regulated that the atmospheric and furnace pressures are so balanced that there is draught inwards or outwards in the furnace. If this is carefully attended to the fire-doors may be opened for cleaning fires or assisting clinkers through the dumping plates without any loss of heat through air admission.

These stokers have a disadvantage that they will only operate satisfactorily with the size and nature of the coal for which they are originally adjusted. That is to say, if the grate is covered evenly when using nuts, the probabilities are that if a slack coal be used without previous adjustment the fire will be carried all to the back of the grate, leaving the front portion bare. The necessary adjustment being made by the alteration to the coal lifters, this cannot be done without shutting down and cooling off the furnace.

With the large type of Underfeed stoker, also, it is not possible to maintain a satisfactory banked fire, as burning of the bars results. Renewals are expensive, and considerable skilled supervision is necessary for good results. On the other hand, this is an excellent machine for obtaining high evaporative duty owing to its capacity for forcing when sufficient mechanical draught is available.

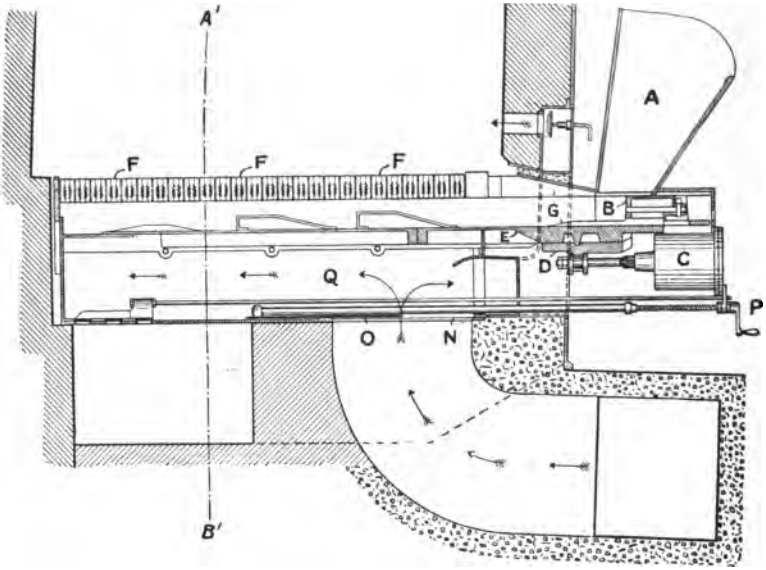


Fig. 22.—" Underfeed " Stoker, Sliding Type (longitudinal section).

A modern stoker, having considerable points to recommend it, is the Erith Riley Stoker, an example of its furnace being shown in Fig. 24. The principle of feed is similar to that of the stokers just described. The coal (usually fine slack) is fed by rams from the upper openings into the troughs between the moving *tuyères*, which are perforated down the sides to supply air to the top of the retorts. After distillation the coke finds its way on to the lower *tuyères*, and thence to the ash pushers and dumping plate. The alternating movement of the *tuyères* and ash pushers keeps the fuel bed open, and also breaks up the clinker before discharging it. Very high efficiency has been obtained on tests with this stoker using low grade slacks, for the economical utilisation of which it appears to be particularly suited.

Chain grates are probably the most widely used of any class of mechanical stoker.

These stokers are supplied in this country by Messrs. Babcock and Willcox and by Messrs. Bennis and Co., the products of each of these firms differing only in minor details. A chain-grate stoker by Messrs. Babcock and Willcox is shown in Fig. 25. It consists of a wide band or chain, the links of which form the grate, passing over a driving sprocket at the front end and over a drum at the back end. The top surface carries the fire, and the underside in returning through the ash-pit is cooled therein by the air draught. Coal is fed on to this grate from a hopper, the thickness of the fire being regulated by a movable shutter, which can be easily adjusted for any fire thickness up to ten inches.

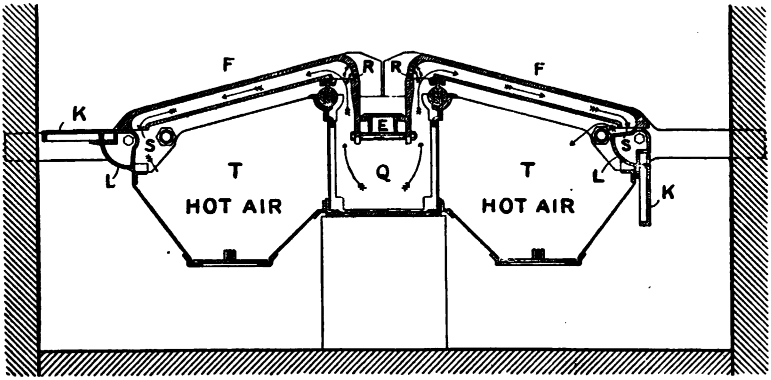


FIG. 23.—" Underfeed " Stoker, Sliding Type (cross-sectional elevation).

The grate is driven through a variable speed-gear running in oil.

Over that portion of the grate nearest to the boiler front a low fire-brick arch is built, in order to distil the volatile matter readily and to ignite the remaining coke.

The coal is gradually consumed, and with proper regulation nothing but ashes should pass over the dumping bars on to the door at the back end. The dumping bars project above the level of the grate surface so as to form a dam, which retards the forward movement of the partly burnt fuel at the back end of the furnace, thus compensating for the reduced fire thickness by causing it to pack more closely together. This prevents loss of efficiency due to excess air.

Chain-grate stokers are, in the great majority of cases, worked

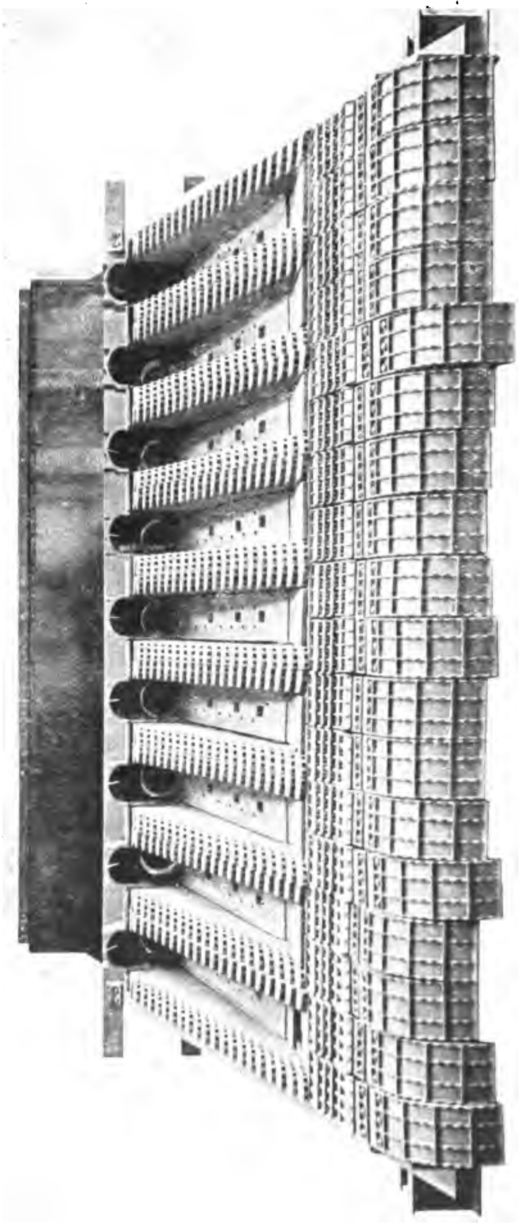


FIG. 24.—Erith-Riley Stoker Fire-grate.

on natural or induced draught only, and do not permit of much forcing of boilers.

When it is desired to work boilers lightly the louvres at the back end of the grate are closed, partly or entirely, thus rendering a large portion of the grate inoperative.

With screened coals the chain-grate stoker keeps very even fires, but when mixed coals (such as "nutty-slack") are used there is great difficulty experienced in keeping an even bed of fire. This is especially the case when the coal is fed into the hoppers through chutes, which is the usual arrangement. The larger portions of the coal, such as nuts, roll out to the sides of the hopper, leaving the fine slack in the middle. On reaching the grate the nuts burn readily, leaving the centre of the grate with the fine coal unburnt. Unless this is spread by hand tools inserted through the side inspection doors of the furnace, it will pass over and be dumped unburnt owing to the air finding its way through the bare portions of the grate. This effect is also accentuated by the friction of the walls retarding the supply of fuel to the sides of the grate.

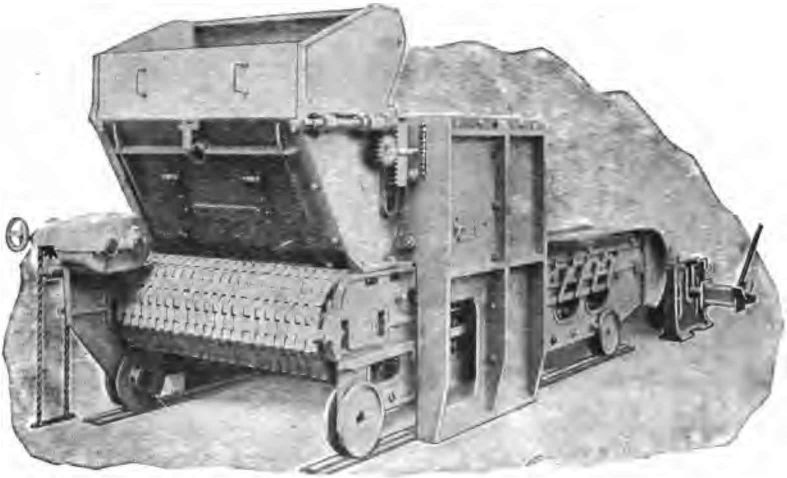


FIG. 25.—B. and W. Chain-grate Stoker.

Baffles have been introduced into coal chutes in some cases, with improved results.

The walls in any case should be frequently sliced with cutting-bars specially made for the purpose. These bars are pushed under the sides of the front apron to do this when the stoker is working.

With a view to providing increased combustion space, chain-grate stokers have in several instances been fitted sloping to a more or less degree from the hopper downwards towards the dumping plates. This arrangement was first introduced to enable a longer grate to be fitted than that for which the boilers were originally designed, and, owing to the improved results in combustion and evaporation obtained thereby, has been adopted as a definite means to obtain greater efficiency in some modern plants.

With fine coals a thin fire with a high speed of grate gives the best results. Thicker fires are used for larger sized coals.

Wetting of Slack Coals.—Theoretically, in moistening coal a loss of efficiency occurs owing to the heat absorbed by the water in evaporating it. In practice, and when using slack coals, this loss is more than counterbalanced by the action of the water first binding the coal together, and then on becoming heated it breaks up the close layer of coal and admits sufficient air to consume it. Dry slack coals become coked more or less hard, and can only be broken up by hand by a slice bar either under the apron or through the side inspection openings.

Comparing hand with mechanical firing, the same technical skill is required for efficient results in either case, but with hand firing considerable manual dexterity is required in addition.

A note should be made of the fact that in firing good quality " nuts " on mechanical stokers, damage to the fire-grates is often caused by the intense heat of the lower layers burning the fire-bars. The reason of this is that insufficient ash is formed to protect the bars from the incandescent heat of the burning fuel.

Hand firing does not give good results with small coal, and is impracticable in connection with the large fire-grates used with some modern water-tube boilers. Chain grates are constructed up to 96 sq. ft. or more per grate, and 12 ft. in length from front to back, the grate area of individual boilers sometimes being as much as 200 sq. ft.

Mechanical stokers do not use large coals, which are generally of a higher calorific value than small coals of the same class; and working in conjunction with economisers, Lancashire boilers can be made to give a very high efficiency with good hand firing.

CHAPTER V

AIR SUPPLY.—Natural draught—Anemometers—Induced draught with steam jets and fans—Forced draught with steam jets and fans—Dampers, arrangement and operation—Flues—Draught gauges and recorders.

NATURAL draught is the description given to the current of gas initiated in a chimney, and caused by the low density gases in the stack rising therein and drawing a current of air through the furnaces to replace them.

The draught thus obtained is measured by the difference of water level shown in a U tube, one leg of which is connected to a pipe inserted into the flue wherever it is desired to make a test, the other leg being open to the atmosphere. Such a gauge is shown in Fig. 26. In taking these draught tests the connecting pipe must project as nearly as possible at right angles to the flow of the air or gases. If this is not done and the tube opening faces the flow of gases reduced readings will be obtained, and with the tube opening in the opposite direction too high a reading will be shown. The draught is measured by the distance between the water surface in each leg expressed in inches and tenths of water.

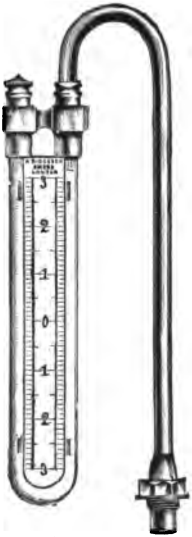


FIG. 26.—U-Tube Draught Gauge.

The draught in a chimney varies with the height of the stack above fire-grate level, and the difference between the temperature within and the atmosphere without. The area of the chimney has no bearing upon the draught at its base, but must be regulated according to the grate area of the boilers with which it is connected.

Since it requires 550° F. temperature in a 90 ft. stack base to maintain ·65 inch draught with 60° atmospheric temperature, it is evident that some considerable proportion of the heat of the coal is used to maintain this draught. With reasonably complete combustion the heat used for producing the draught, by maintaining 550° F. at the stack, will be 16% of the total coal burnt on the grate. With 0·6 inch of draught at the dampers of a Lancashire boiler, the draught over the fires, with clean and well-designed flues, will be about 0·3 inch, this being the minimum allowable if sufficient air is to be obtained to secure complete combustion on a 6 ft. grate.

When an economiser is installed it will reduce the draught at boiler dampers by about 40%, owing to reduction of the final temperature of the gases, friction and draught leakages through chain holes, etc. In this case, if it is not possible to provide a new chimney (which in the case under consideration would need to be about 130 ft. high), some assistance must be provided for the draught, as will be described later in this chapter.

In order to find out definitely whether the air supply is sufficient it is first necessary to ascertain the pounds of coal burnt on the grate per hour. The volume of air is obtained by means of an anemometer (Fig. 27) which has a meter index reading in feet.

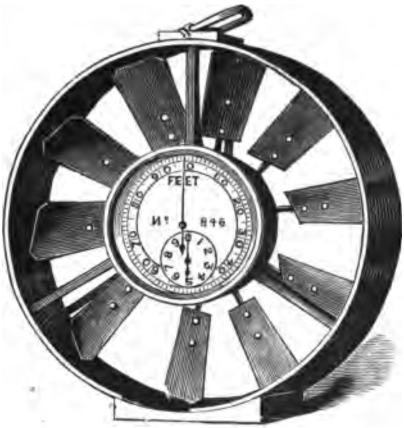


FIG. 27.—Anemometer.

To obtain an anemometer measurement the instrument is held for, say, two minutes in varying positions in the current of air to be measured. The reading thus obtained is multiplied by the area in sq. ft. of the opening through which the air is passing (say the segmental front opening of a Lancashire boiler ash-pit), and by thirty—when the test is of two minutes' duration—to give the cubic feet of air per hour (1 cubic ft. of air at 62° F. weighs 0·0761 lbs.), then—

$$\text{lbs. of air per hour} = \frac{A \times V \times \frac{60}{T}}{0{\cdot}0761}$$

where A = area of opening in sq. ft.,
V = velocity of air in ft. per minute,
T = duration of test in minutes.

The quantity of air in lbs. theoretically required to burn a pound of coal is given by the following formula, viz.—

$$A = 0{\cdot}116\ [C + 3\ (H - \tfrac{1}{8}O)]$$

where A is the quantity of air in lbs.,
C, H and O, the percentages of carbon, hydrogen and oxygen in the coal respectively.

These percentages are obtained by ultimate analysis, which needs the services of an expert analytical chemist to carry it out.

INDUCED DRAUGHT

Induced draught to aid or replace natural or chimney draught is obtained with a fan installed in the main outlet flue from a boiler or group of boilers. In the case of locomotives and small vertical and similar boilers a steam jet is employed in the smoke-box or chimney to produce a strong draught by an "injector" action. In the case of locomotives this is used to maintain the draught through the fires while stationary, and in the small stationary or crane boilers for "drawing" the fires up after firing, as the feeble natural draught is generally insufficient.

In modern power-houses the use of natural draught is being discarded, as its employment would necessitate the use of a great number of very large chimneys to deal with the grate areas obtaining on modern water-tube boilers in conjunction with economisers. In such cases the draught is obtained by means of an encased fan, which draws the flue gases through it, discharging them into a comparatively short up-take or chimney.

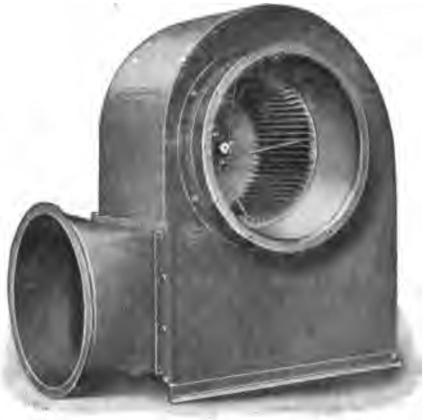


FIG. 28.—"Sirocco" Induced Draught Fan.

The well-known "Sirocco" induced draught fan is shown in Figs. 28 and 29. Fig. 28 shows the disconnected fan from the suction inlet side, with arrangement of the "runner" blades clearly defined, and Fig. 29 is a similar fan coupled to a motor for electric drive. The fan bearing is water-cooled to prevent over-heating from heat conveyed along the shaft from the fan blading.

The great advantages of induced over natural draught are greater ease of regulation, with consequent improvement in fuel economy; independence of atmospheric changes; reduction of space required for installation; the low final temperatures (sometimes as low as 250° F.) that can be worked with, which indicates the very highest efficiency when not due to large excess of air or leaky settings.

With small batteries of boilers working in conjunction with economisers, the relative cost of a suitable chimney to the whole job is so high, if sufficient draught is to be maintained with low final temperatures, that an induced draught fan is essential to the maintenance of high efficiency.

Forced Draught

Both steam jets and fans are very largely used for forcing air under pressure through the close fire-grates necessary in burning slack coals.

Steam jets, whether for mechanically or hand-fired furnaces, have some objectionable features. The injection of steam into the furnace increases the production of the acid sulphur products, with consequent accelerated wasting of economiser pipes. The consumption of steam is very often excessive unless the jets have constant attention and are renewed very frequently. Serious corrosion of the furnace tube plates of Lancashire boilers, owing to the moistening of ashes accumulated behind the front cover of ash-pit opening, has also been caused in many cases; this taking place when the blast is turned off and leakage takes place past the controlling valves.

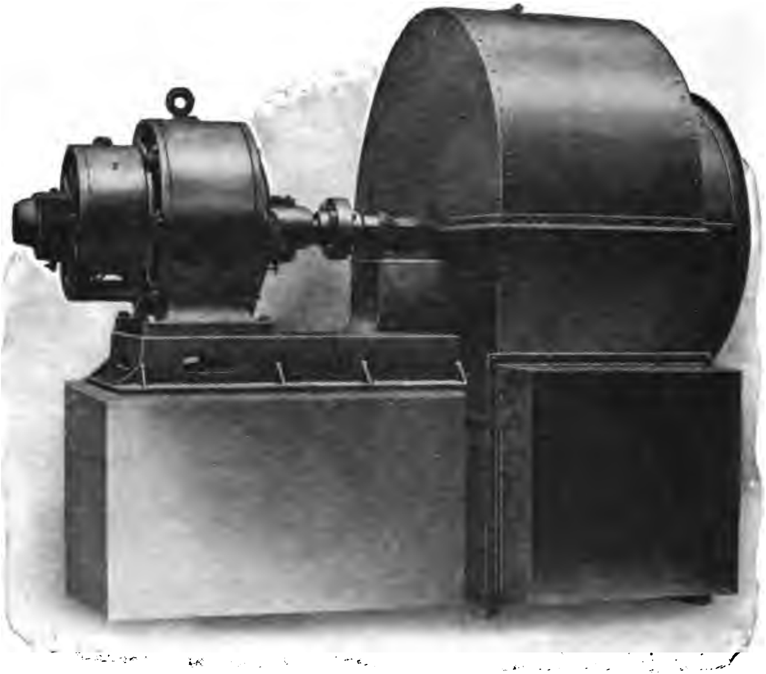


Fig. 29.—" Sirocco " Induced Draught Fan.

If care and attention are given to the points enumerated above, an arrangement of steam jets certainly forms a very convenient and cheap method of obtaining additional air pressure under the grates, but fan draught is to be preferred wherever it is possible to instal it.

The advantages of forced draught are that a very high rate of combustion can be obtained with thick fires. It also reduces the loss of heat through leaky settings. With fine coals, refuse, anthracite, Welsh steam coal, etc., it is essential, as even mechanical induced draught cannot obtain the high air pressure under the grate necessary for properly burning such fuels.

When using mechanical draught care must be taken that this is not excessive, or the fuel will be lifted from the grates, resulting in bare patches and excess air.

The fans used for forced draught are of similar design to those installed for induced draught and need no special description, except, of course, that the inlet side is open to the air and the delivery port discharges beneath the grate.

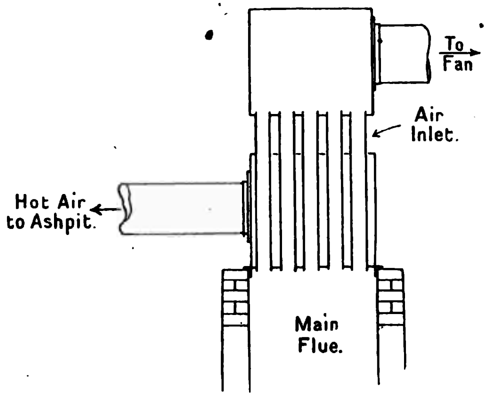


FIG. 30.—Air Heater.

These fans are used for such mechanical stokers as the Underfeed, Erith-Riley, " Koker," etc.

PRE-HEATED AIR

The use of the heat of waste flue gases has in many places been utilised for raising the temperature of the air before it reaches the fire-grate. The Ellis and Eaves air heater is shown diagrammatically in Fig. 30. The flue gases pass through vertical tubes, around which the air is drawn into the hot-air box, and thence to the fire-grates by the air trunks. The reduction of temperature in the flue gases is only about 120° F. with the air heating system, in comparison with economisers which, when properly proportioned, show a reduction of about 200° F., representing a better heat recovery equal to 83% increase.

If an air pre-heater of the type described has too large a number of tubes, the centre section of tubes is very likely to become overheated owing to the inability of the air to penetrate so far, all the air being absorbed by the outer zone. On the other hand, the bulk of the flue gases will pass up through the centre tubes with insufficient cooling, resulting in damage to the tubes and a poor air-heating effect.

In industrial undertakings, such as steel works, where boilers are often installed close to reheating furnaces, a large fuel economy may be obtained by using the heat of the waste gases from the furnaces to heat water by means of an economiser, and the waste heat of the boilers to pre-heat the air as described above.

It is, of course, possible to arrange the economiser and air heater in the reverse position to those indicated, but this is not so convenient owing to the large size of the pipes required to carry the pre-heated air from the heater to the fire-grates. The arrangement as suggested probably indicates the highest degree of economy possible when working with direct fired boilers, and should be adopted wherever it is practicable. If there is sufficient waste heat available, boilers should be installed direct in the exit flues of the furnaces, as will be described later in this work.

DAMPERS

The operation of dampers is a most important consideration, and very rarely receives proper attention.

It is only in the largest plants that induced draught fans are installed on individual boiler units, and natural draught is rarely, if ever, used in this way. It follows, therefore, that in the majority of cases there is necessity for means to regulate the air supply of each boiler independently of the rest of the battery, so that each fire may have its air supply properly proportioned according to its condition. This damper regulation cannot be replaced by a common damper in the main flue or a common fan regulator.

Assuming that we have three or more similar boilers connected to a main flue with a good draught which is obtained from a fan or chimney at one end; to get evenly distributed work from all the boilers it will be necessary to lower the dampers on the boiler nearest the stack, the dampers of the boilers being opened more as they are farther removed from the stack. Otherwise if all the dampers were equally open the greater draught would pass through the grate nearest the stack, with corresponding reduction on the remaining grates. With fire-grates equally covered, a draught-gauge on the boiler side of each damper will indicate when there is an equal pull upon all the fires.

Also when fires are being cleaned, the dampers of the boiler should be eased down to minimise the waste of heat caused by the rush of air through the flues, and also to preserve the draught on the other boilers, which would be otherwise considerably reduced.

The arrangement of dampers should be such that they can be worked easily from the firing-floor without undue exertion, for human nature, as exemplified by the average fireman, will dictate a non-observance of these points if they involve inconveniences that will not cause serious results if neglected.

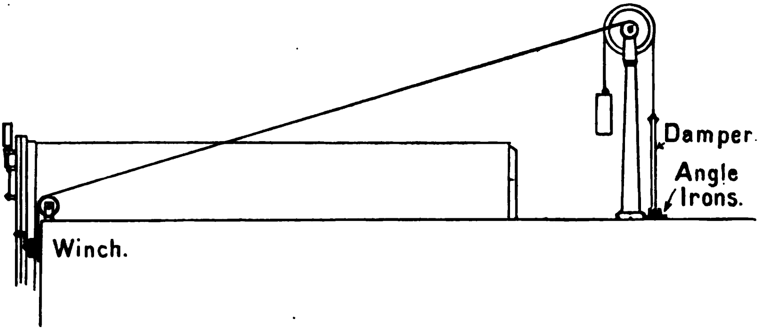


FIG. 31.—Operating Gear for Sliding Dampers.

At any rate, the most conscientious man will not climb over his boiler to lower the dampers for cleaning fires, so the provision of means for doing this from the boiler fronts is imperative; for it is useless to expect economical results without this elementary requirement being observed.

The practice of regulating the air supply at the ash-pit opening is a most uneconomical practice, since by closing the furnace front entirely, cold air is drawn into every crevice and other opening in the boiler settings to a greater degree than when the boiler is actually working, as the full draught is applied to every part of the boiler flues when the dampers are open and the furnace front blocked up.

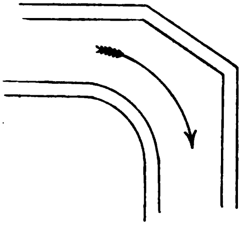


FIG. 32.—Construction at Corner of Flue.

An arrangement for easily operating sliding dampers of the usual form from the boiler front is shown in Fig. 31. The two damper pulleys of the Lancashire boiler are keyed on to one shaft and lined up so as to work easily. The shaft is extended through one of the pulleys, and on this extension a small drum

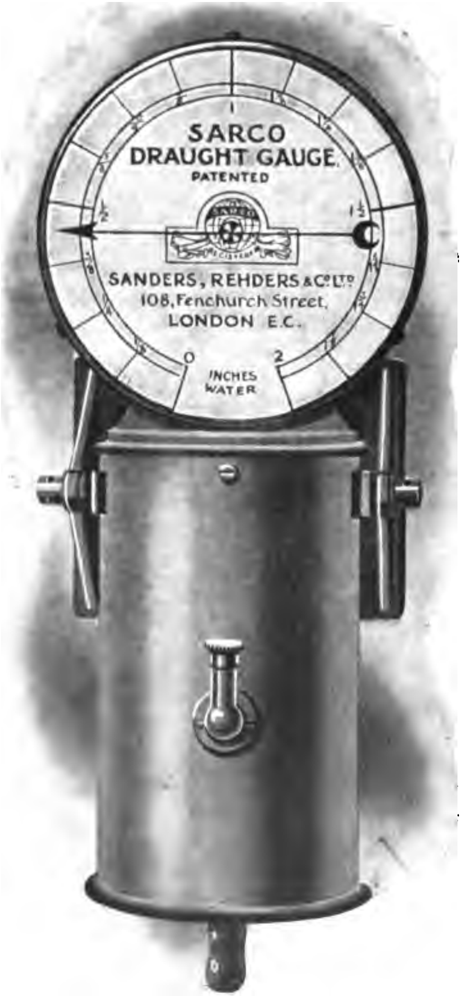


FIG. 33.—" Sarco " Draught Gauge.

is fitted. This drum is connected by a ¼ in. wire rope over a jockey pulley to a small arc lamp winch mounted at the side of the boiler front or other convenient position. The damper weights are lightened somewhat so that the dampers close when the rope is slacked out; the only load carried by the ¼ in. wire rope being the difference between the dampers and counterweights.

In the sketch (Fig. 31) an arrangement for air-sealing sliding dampers will also be noticed. On each side of the damper is a length of 2 in. × 2 in. angle iron, these two angles being arranged to make a loose fit on the damper plate by means of a bolt and a square distance piece at each end. A great loss of draught is often caused by not closing the opening between the damper and the slot in which it works. This is practically cured by such a device as that shown. The angles must not be secured, but must be left free to rise with the damper in case the latter becomes buckled.

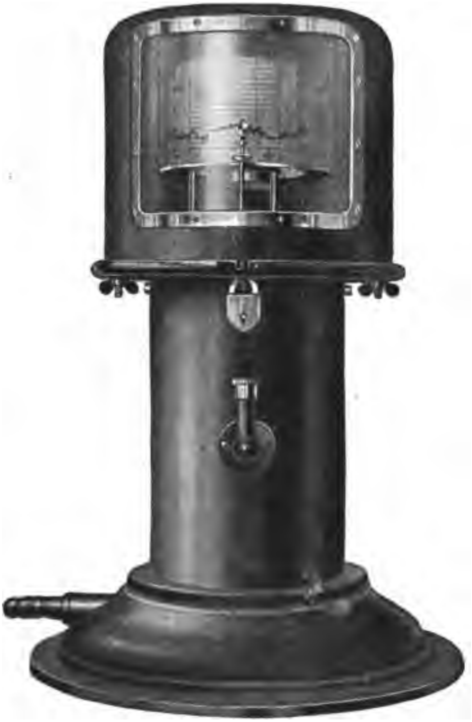


FIG. 34.—" Sarco " Draught Recorder.

FLUES

Faulty flue construction and design are often accountable for shortage of draught on an otherwise well arranged boiler plant.

Flues should be of ample area, and bends should be avoided wherever possible.

Convenient means of access should be provided for examination and cleaning, and wherever a swing damper is installed, a cast-iron hinged door should be built into the flue wall, so that in case of the damper becoming fast it may possibly be eased by " persuasion " through the open door without cooling the whole plant down. This point is very important in connection with economisers, which may have to be shut off from the flue at any time, and if the dampers cannot be moved serious difficulties may arise.

The corners of flues round which the gases have to pass should be opened out to a wider area, as shown in the sketch (Fig. 32), to compensate for the additional friction. The space available does not always permit of this arrangement, but wherever it can be done the corners of flues should be " eased out " as shown.

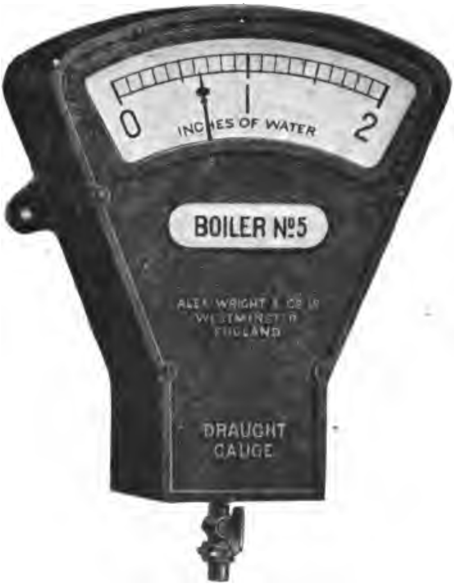


FIG. 35.—Draught Gauge by Messrs. Alex. Wright & Co., Ltd.

Flues should also be constructed so that the gases are delivered at the boiler damper level direct into the stack, and must not be carried down underground; as in addition to reducing the draught there is also risk of dampness, which in absorbing heat to evaporate it reduces the temperature of the gases, with corresponding loss of draught in the chimney.

The path of the gases should, as far as possible, rise towards the chimney, and in any case never be diverted downwards.

In some modern electric power plants the gases rise practically continuously upwards, the economiser being installed directly over (or superposed upon) the boiler, and the induced draught fan above that. This virtually amounts to the economiser becoming to a certain extent a part of the chimney, and thus reducing the fan power required, with consequent economy in consumption of driving power.

DRAUGHT GAUGES

The ordinary U-tube draught gauge has already been described, and although this is very largely used as a fixture, the indication is not conspicuous and open enough to be a satisfactory instrument for boiler-house use, although it is simple, inexpensive and accurate.

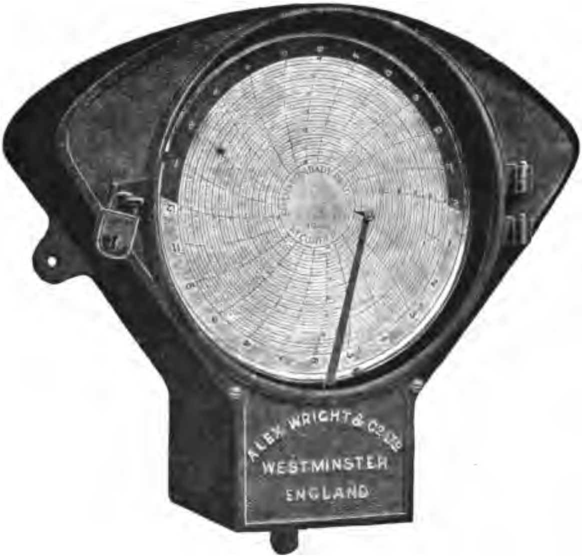


FIG. 36.—Draught Recorder by Messrs. Alex. Wright & Co., Ltd.

Among large-scale indicating draught gauges may be mentioned the " Sarco " (Fig. 33). The pointer is actuated by a pinion operated by a rack rod attached to a hollow metal float in the chamber seen at the bottom. The pipe connection to the flue is made at the nipple at the bottom of the float chamber, which is filled with light oil. An internal pipe rises from the nipple inside the float above oil level. The draught exerts a pull upon the float, which is communicated to the dial pointer by the rack and pinion before mentioned. A similar instrument arranged as a recorder is shown in Fig. 34.

The " Simmance-Abady " indicating and recording draught gauges are shown in Figs. 35 and 36 respectively, these deriving their operation from a metal corrugated "diaphragm" on the principle of the aneroid barometer. The draught is applied to the inside of the diaphragm chamber, which, being flexible, contracts slightly, this movement being transmitted to the scale pointer or recorder pen by an arrangement of levers.

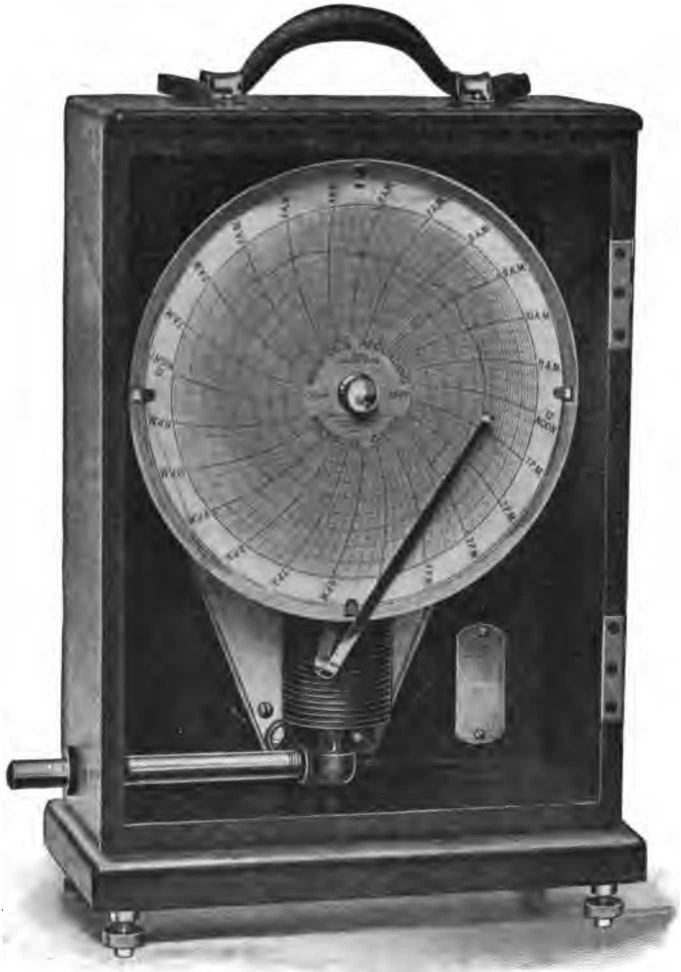


FIG. 37.—Bristol Portable Draught Recorder.

Another recorder on the aneroid principle is the Bristol, shown in its portable form in Fig. 37. Other patterns are made with plated cases, and also watertight types for dusty and damp situations for permanent connections.

The value of indicating draught gauges lies in the fact that most boilers give their best results with a certain degree of draught in the flue. If increase of draught is required with similar coal it is an indication that the boiler flues need cleaning. Therefore, as a guide to proper damper regulation, the draught indicator may very materially assist in the matter of efficient operation. Recorders not only of draught but also for all other measurements are necessary as a guide to the superintendent or other engineers as to what conditions have existed throughout the twenty-four hours, as he manifestly cannot be personally present at all times. As an aid to investigation of working results recorders are practically indispensable, as a set of charts of various measurements will enable the engineer to ascertain with great certainty the degree of efficiency obtained and the conditions obtaining at any moment. Therefore by means of such records it is possible to trace sources of loss with the utmost facility, whether due to faulty or careless operation or defects in the plant itself.

CHAPTER VI

FURNACE AND FLUE GASES.—Composition—Testing of gases—The Orsat Apparatus—CO_2 Thermoscope—Typical CO_2 indicator and recorders—Temperatures of waste gases—Pyrometers and pyrometry—Application of draught, analysis and temperature tests of flue gases—Losses in flue gases.

AIR, as we have seen, consists of 79% nitrogen and 21% of oxygen. The volume of the flue gases leaving the dampers of a boiler being the same as that of the air passing through the furnace, the nitrogen is still 79% as before, and with theoretically perfect combustion the remaining 21% will be CO_2 (carbon dioxide), as already described in Chapter III.

In practice, with solid fuel a considerable excess of air is necessary to ensure complete combustion, and an analysis of the gases showing—

Nitrogen	79%
CO_2	15%
O	6%

will indicate very efficient working indeed. CO (carbon monoxide) is not usually found in flue gases in any considerable amount, as it is usually consumed before reaching the dampers. Unconsumed volatile matter or black smoke (unburnt carbon) are more likely to be present than CO, high apparent readings of the latter gas usually being due to inaccurate operation of the Orsat apparatus used.

With the following analysis—

Nitrogen	79%
CO_2	10%
O	8%
CO	1%

the balance of 2% may be taken as unburnt hydrocarbons. Although sufficient air is present for complete combustion, the fires have been cooled down by putting fresh coal on at too long intervals, so that the glowing fuel remaining is insufficient to provide heat for igniting the fresh charge.

The apparatus used for analysing the flue gases is the Orsat apparatus, shown in its complete form in Fig. 38, and as a diagrammatic sketch in Fig. 39.

It consists essentially of three pipettes, A, B and C, containing absorbents for CO_2, O and CO respectively; a burette D, graduated in 100ths for measuring the volume of the gases before and after absorption in each of the pipettes. This burette is water-jacketed as an insulation from external variations of temperature. H is a tubulated bottle connected by a flexible rubber tube to the bottom of D and contains water, by means of which a charge of gas is drawn into D and also passed into the various pipettes. The front bulb of each pipette is filled with thin glass tubes, and in addition each tube in C has a spiral of copper wire within it. The back bulb of the pipette is open to atmosphere. On the neck of each front bulb a mark is provided which indicates the level at which the absorbent must be at commencement and completion of each analysis. The pipettes are each connected through a glass stopcock (which must be kept greased) to the horizontal tube E, which is connected at one end to the top of the burette D, and at the other through a three-way cock F, and cotton wool filter I to the flue. To a T-piece in the flue connection the rubber bellows G is attached for the purpose of exhausting all air from and to draw in a charge of gases from the connecting pipe leading from the flue to the "Orsat."

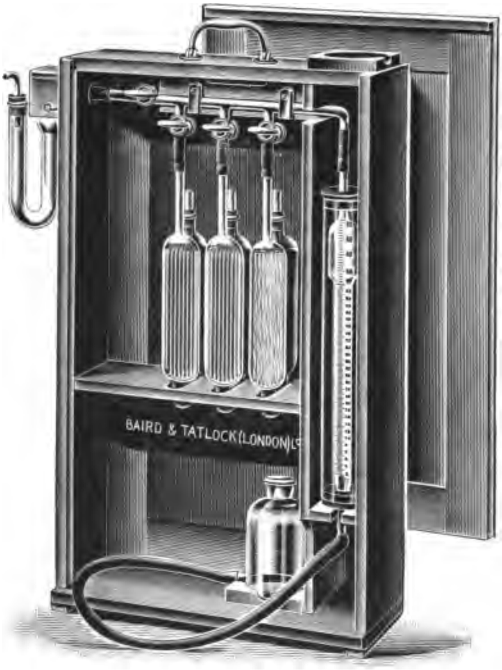


Fig. 38.—Orsat-lunge Apparatus complete.

The absorbing agents for the pipette A, B, and C are made up as follows—

A contains a solution of 1 part of caustic potash in 2 parts of water, which absorbs CO_2.

B contains a solution made by dissolving 5 grammes pyrogallic acid in 15 c.c. of water mixed with 120 grammes of caustic potash dissolved in 80 c.c. of water. (This solution dissolves O.)

C contains a saturated solution of cuprous chloride in hydrochloric acid, for the absorption of CO.

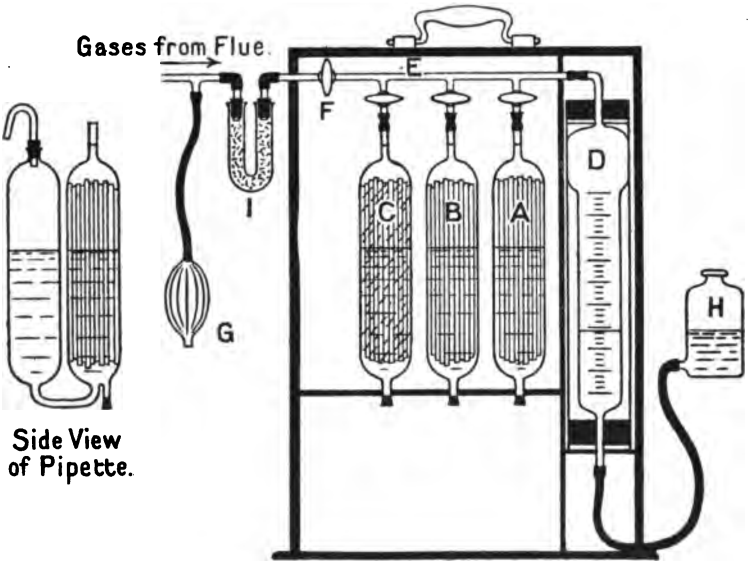


FIG. 39.—Diagram of Orsat-lunge Apparatus.

N.B.—Solution B must be made up immediately before use and not be unduly exposed to the atmosphere, as this will lead to premature exhaustion through absorption of oxygen from the air.

Fill A, B and C about half-full or slightly more with the respective solutions.

The bottle H contains sufficient water to ensure that on raising it so that the water reaches the top of the burette D, the outlet tube of the bottle does not become uncovered.

These arrangements completed, the Orsat is ready for use.

TO USE THE ORSAT APPARATUS

A small bore (say ¼ in.) iron or copper tube is inserted through a hole made in the flue, well into the current of gases to be analysed. The space between the tube and the hole in the brickwork must be carefully and tightly packed with rag in order to exclude any indraught of air. The portion of the tube projecting externally is connected to the open end of the glass tube E through the filter I and the three-way cock F.

Now see that the various absorbents reach the mark in the neck of their respective pipettes. If this is not so, draw them up to the position by raising H until D is about half-full, thus expelling some of the air through F. Close F and open the cock on the pipette it is required to adjust, and then H is carefully lowered until the liquid exactly reaches the mark, at which point the pipette cock is closed. In carrying out this adjustment the greatest care must be taken not to draw any liquid up into the tube E.

Work the bellows G for a minute or so, first seeing that F is in such a position that E is connected to atmosphere. There is a mark or " pip " on the handle of F to indicate which tube (if any) is connected to the atmospheric outlet; the first position is with the handle at right-angles with the mark to the right.

With all three pipette cocks closed and E connected to atmosphere, raise H until water reaches the 100% mark in D. Connect E to the flue pipe and lower H, so that water in D indicates 0%; connect E to atmosphere again and expel this charge by raising H. Repeat three times and then, starting with the water exactly at 100% and E connected to the flue, lower H till the water is well below 0% in D. Holding the bottle H very steadily, open E to atmosphere and raise the bottle carefully until water is exactly at 0%, and then shut E off from flue.

The following operations must be carried out exactly in the order named, for, as we have seen, A absorbs CO_2, and as B also contains caustic potash in addition to the pyragallol, it will absorb CO_2 as well as the O for which it is provided. In the same way solution C absorbs both CO and O.

Now open cock on A and move H steadily up and down so that the surface of the liquid in A travels from the top to the bottom of the tubes, and no further, at each raising and lowering of H. Repeat four times and finish with liquid A exactly at the mark in the neck of the pipette as at the commencement, then close the cock.

Hold H closely to the burette D, and so that the surfaces of the water in each correspond exactly, and read off the percentage of CO_2 on the scale.

Repeat the process in pipette B, passing the gas sample at least seven times into and out of the pipette, as this solution does not absorb the oxygen so rapidly as CO_2 is absorbed by the caustic potash. Neglect of this precaution, no doubt, accounts for high apparent readings of CO in flue gases where little or none is present, the unabsorbed oxygen from B being carried over and absorbed by C and read off as carbon monoxide (CO), for which it is provided.

The Orsat apparatus thus indicates firstly, by the measurement of the CO_2, to what degree combustion has been carried, and it may be definitely stated that the percentage of this gas detected is a true measure of the degree of combustion attained. If the CO_2 is deficient the percentage of O is an indication of the amount of excess air in the gases, admitted either by way of the grate or through leaky brickwork. Presence of CO is an indication of incomplete combustion, and will only, as a rule, be present with deficient air. The existence of unburnt hydrocarbons, usually caused through incorrect firing, may be taken for granted if the sum of the readings of CO_2, O and CO + 79% for the nitrogen do not total up to 100%. Confirmation of this will usually be available in the form of smoke issuing from the chimney.

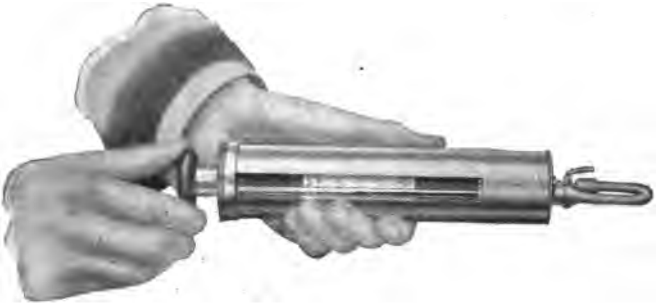


FIG. 40.—CO_2 Thermoscope.

It will now be seen that if the percentage of CO_2 is known, this alone is sufficient indication of the conditions of efficiency as regards *combustion*, but it affords no indication by itself of the over-all efficiency of the boiler plant. This will be discussed in the latter part of this chapter when dealing with combined readings of CO_2, temperatures and draught.

The great importance of taking frequent readings of the percentage of CO_2 in the waste gases is being more and more recognised, and to enable this to be readily done a more portable apparatus than the Orsat is desirable, this latter being retained as a standard instrument for checking purposes. A suitable apparatus for this purpose is the

CO_2 Thermoscope.

This handy appliance is shown in Fig. 40, and is supplied by the Underfeed Stoker Company. It depends for its action upon the principle that every chemical action is accompanied by the generation of heat, the consequent rise to temperature being in exact proportion to the amount of chemical reaction or change that has taken place. In the apparatus we are considering the chemical reaction utilised is the absorption by an accurately weighed charge of caustic soda of the CO_2 contained in a measured quantity of flue gases passed through it by a hand-pump.

The "Thermoscope" consists firstly of a pump, the nozzle of which is fitted with a small three-way cock, which fulfils the function of the three-way glass cock of the Orsat apparatus. The tubulated bottle of the Orsat is represented by the hand-pump. After exhausting the pipe connection by means of the pump, the final sample is passed through a small copper cartridge containing caustic soda inserted within the hollow bulb of a special thermometer with an adjustable scale graduated to read in percentage CO_2. The wooden knob of the pump handle has a circular recess within which a steel point is provided for puncturing the cartridge at each end before use. The stem of the pump-handle has a small ordinary thermometer encased in it, by which the size of the gas sample is determined, the stem also being graduated in °F to provide compensation for variations of temperature.

This apparatus is so simple that an intelligent stoker can be taught how to use it without difficulty.

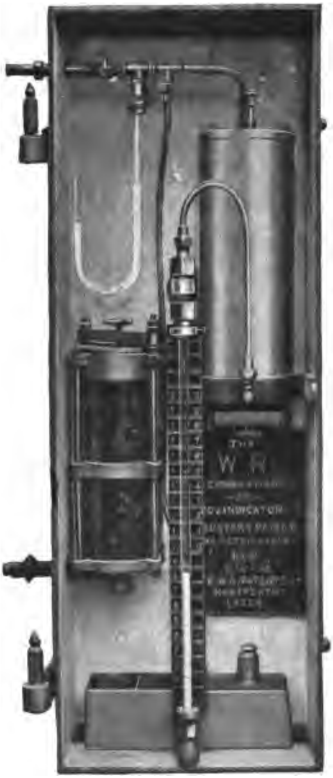


FIG. 41.—W.-R. Combustion Indicator.

W.-R. CO_2 Indicator (*Fig.* 41).

As a guide to the fireman this is a valuable instrument, and is useful where no permanent record is desired, and the manufacturers (the W.-R. Patents Company) do not recommend a recording attachment, although an ordinary recording draught gauge, with charts graduated in $\%CO_2$, would seem to be applicable.

A diagrammatic sectional sketch of the instrument (which is of robust construction) is shown in Fig. 42. Its action is as follows: A small steam injector S aspirates a sample of the gases, which passes through the filter F round a porous pot P. Some of the gas penetrates the pores of the pot and becomes absorbed by the dry reagent contained in the cartridge R. The vacuum produced by S will, therefore, vary according to the amount of CO_2 absorbed in R, and this vacuum is indicated on the glass water column G, which is graduated in % CO_2. As already mentioned, this provides no check upon the working of the plant throughout the day, and its value mainly lies in its utility as a guide to the fireman.

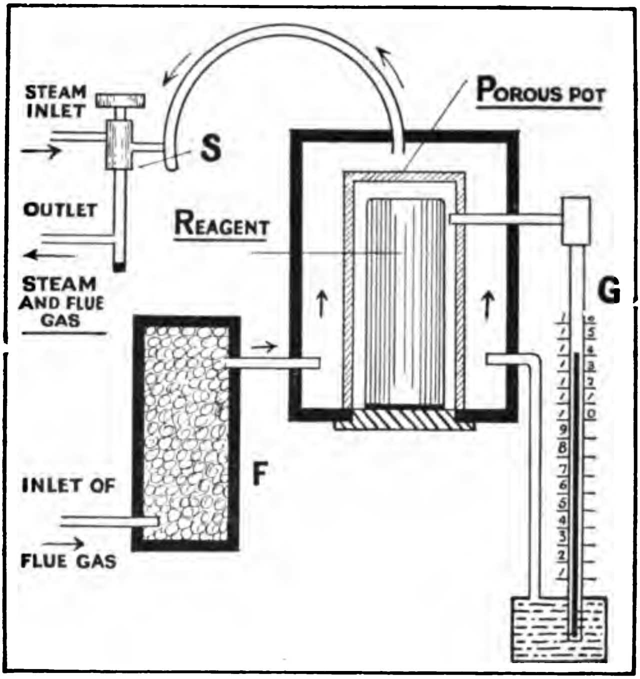


FIG. 42.—Diagram of W.-R. Combustion Indicator.

For a continuous record for the information of the superintending engineer, one of the various types of CO_2 recorders is necessary, and some well-known examples will now be mentioned.

The Sarco CO_2 Recorder (Fig. 43).

This is a very well-known and widely used apparatus for CO_2 measurement. Its action depends upon the absorption of CO_2 from a sample of gases by caustic potash. Samples are extracted at frequent intervals from a by-pass pipe from the flue to the chimney by means of an automatic siphon arrangement. The difference between the volume of the gas sample before and after absorption in a caustic potash solution is recorded on the twenty-four hour chart as a vertical line, the longer the line the smaller being the percentage of CO_2 present in the sample.

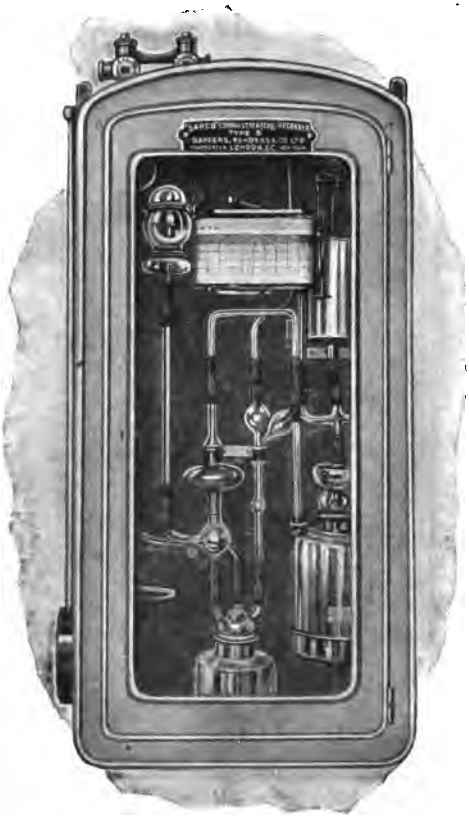


FIG. 43.—" Sarco " CO_2 Recorder.

The Simmance-Abady Combustion Recorder (Fig. 44).

In this recorder the gas sample is extracted from the flue by means of a water ejector, the actual measuring and absorption device being operated by a siphon arrangement. The absorbent is caustic potash solution as before, and the record is made upon a similar chart to the " Sarco " already described. The apparatus is supplied by Messrs. Alex. Wright.

The Bi-Meter CO_2 Recorder (*Fig.* 45).

The recorder manufactured by the Cambridge Scientific Instrument Company, and known as the "Bi-Meter," consists, as its

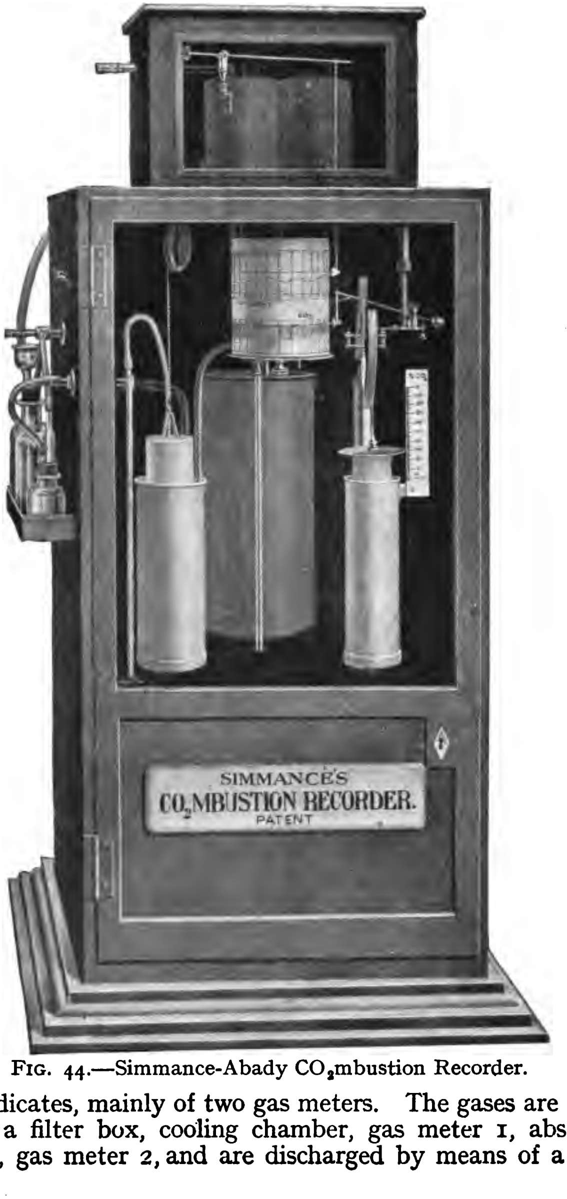


FIG. 44.—Simmance-Abady CO_2mbustion Recorder.

name indicates, mainly of two gas meters. The gases are drawn through a filter box, cooling chamber, gas meter 1, absorbing chamber, gas meter 2, and are discharged by means of a water ejector or aspirator. The absorbent is dry slaked lime, and the reading of CO_2 is obtained from the difference in the rate of revolution of the two gas meters recorded by the differential gear connected between them.

Temperature of Waste Gases.

With properly regulated fires and air supply, combustion of the fuel should be complete a very considerable distance before the waste gases reach the main flue. Therefore it is quite possible to obtain excellent results as regards CO_2, yet at the same time the efficiency of the boiler plant may be very low. In order to ascertain approximately the efficiency of the plant, as distinct from the efficiency of combustion alone, which is shown by CO_2 apparatus, some measurement of the absorption of heat by the boiler is required. The heat transferred from the gases to the water contained in the boiler is governed by the following conditions, viz.—

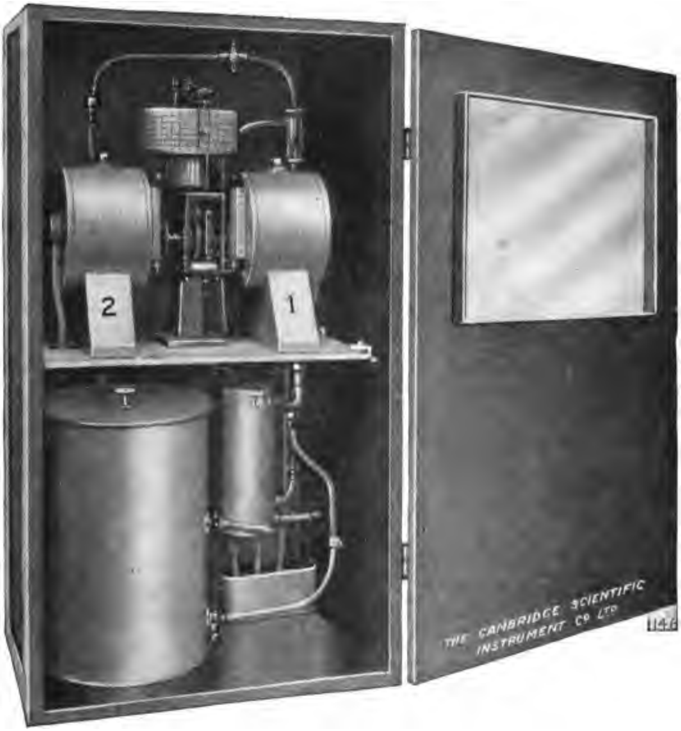


FIG. 45.—Bi-Meter CO_2 Recorder.

1. The cleanliness or otherwise of the boiler plates.
2. The velocity of the gases.
3. The degree of incandescence of the gases or amount of heat in the " radiant " form.

Before proceeding to detail the tests and apparatus used in ascertaining flue temperatures, attention should be given to the diagram, Fig. 46. This shows a Lancashire boiler plant and economiser with the positions in which holes should be provided for testing of gas temperatures, draught and gas analysis. Fig. 47 shows an outline elevation of a Stirling and a Babcock and Willcox boiler with similar holes indicated. The holes in the flues of Lancashire boilers should have small circular cast-iron lids to exclude air when not in use, and the holes into the water-tube boiler flues should have screwed iron pipes built into them with a socket and plug for a similar purpose.

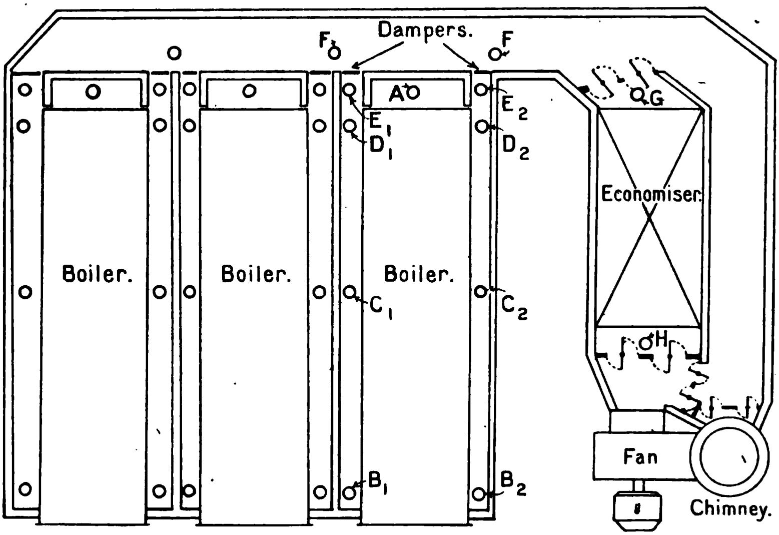


Fig. 46.—Plan of Test Holes.

In Fig. 46 the holes are indicated in the following positions—

A in downtake flue.

B_1 and B_2 at entrance to side flues.

C_1 and C_2 at centres of side flues.

D_1 and D_2 at the end of side flues about 8 in. back from end of boiler.

E_1 and E_2 about 1 ft. before the gases reach the dampers.

F, F at points in the main flue opposite the dividing walls of the boilers and near to the boiler walls of the flue.

G at economiser inlet.

H at economiser outlet.

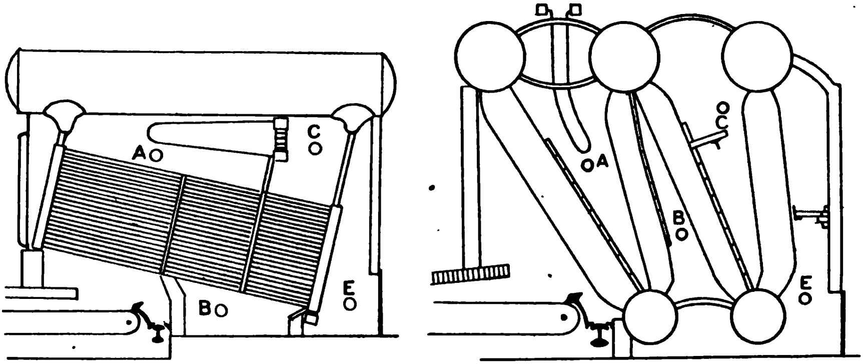
Holes placed as shown in the sketch and described above will provide a means of taking a complete series of tests for draught, temperature and analysis of gases, the results of which will indicate clearly where any defects in the brickwork or operation of the boiler are existent.

In water-tube boilers the position for testing facilities are at the middle chamber, dampers and economiser inlet and outlet flues and intermediate points.

Locomotive boilers require a test-hole in the smoke-box.

Marine boilers require test-holes in the combustion chamber and smoke-box, though it is hardly practicable (except in the dry-back type) to obtain access to the combustion chamber.

The above notes will suggest the appropriate positions of test-holes for those types of boilers not mentioned.



B.&W. Boiler. Stirling Boiler

Fig. 47.—Position of Test Holes.

Pyrometers and Pyrometry.

A pyrometer is the name given to a high-reading thermometer especially constructed for measuring such temperatures as may be found in furnaces or boiler flues.

The two forms generally in use are the mercurial and electric pyrometers; the electric pyrometers being divided into thermo-couple and resistance types.

For temperatures up to 850° the mercurial pyrometer is suitable, and consists of an ordinary mercury thermometer with a specially long stem which is encased in asbestos to just above the bulb, and also has a protecting metal sheath beyond which the bulb protrudes. The bulb is protected by a metal cage or a perforated extension of the sheath. The scale, graduated to 1000° F., is fixed to the upper end of the tube. These mercurial thermometers should only be used for testing the temperatures of exit gases from boiler flues at and beyond the dampers (D, E, F, G, and H. Fig. 47).

A mercurial pyrometer by the Cambridge Scientific Instrument Company is shown in Fig. 48, and is provided with a clamp-on flange for sealing the opening into which the thermometer is inserted. Several of these thermometers should be obtained, owing to the necessity for simultaneous readings at various points. Each pyrometer should have a leather case for protection when not in use.

The stem of the instrument can be obtained in any convenient length, the 4 ft. stem being the most useful.

Electric Pyrometers.

For temperatures up to 1800° F. the thermocouple pyrometer is suitable, and may be used in any position of the flues of a boiler. The action of this instrument depends upon the electrical pressure set up when two wires, each of a different metal, are joined at one end which is exposed to heat. The P.D., or voltage, obtained is measured upon a voltmeter or indicator, the scale of which is graduated in degrees F. or C. as required.

A "Titan" pyrometer and suitable portable indicator are shown in Figs. 49 and 50 respectively, the length of the former being supplied to any requirement. Connection between the two components is made by means of a length of twin flexible cable, and this is preferably steel armoured to protect it against damage.

It is as well to specify a quartz or porcelain protecting tube within the iron sheath of the pyrometer "rod," as this will prolong the life of the instrument. A number of these rods may be used with the one indicator so long as they are all of the same construction as regards the elements of which they are composed.

Resistance thermometers are not so convenient and are not portable, as they require an accumulator to operate them; though where a very large range of temperatures to a

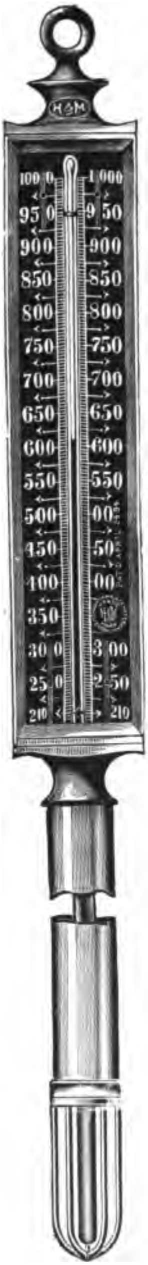


FIG. 48.—Mercurial Pyrometer.

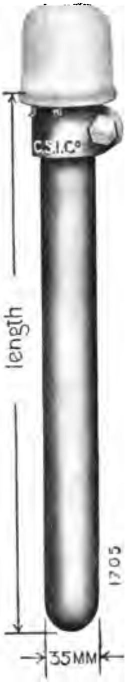


FIG. 49.—Titan Thermo Couple.

maximum of about 600° F is required, they are sometimes installed as fixtures. Their use in this connection will be discussed later on in this book.

To use the pyrometer (either mercurial or electric) it is inserted in the path of the gases to be tested, the temperature being taken when the reading upon the scale is steady. Great care must be taken to exclude any indraught of air around the stem by way of the test-hole, as if this occurs quite erroneous readings will be obtained.

The correct instrument for measuring furnace temperatures is a radiation pyrometer, which in the Féry pattern consists of a small thermo-couple set in a form of telescope arranged so that the radiant heat of the furnace can be focused upon it by means of a concave mirror. The elements of the thermo-couple are connected by a flexible twin cable to an electrical indicator of somewhat similar pattern to those described in connection with the lower temperature thermo-couples.

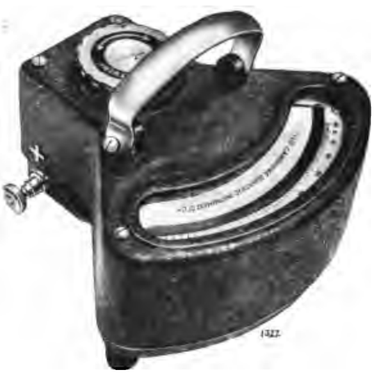


FIG. 50.—Indicator for Electric Pyrometer.

The colour and brilliancy of the luminous gases also form a guide, and an experienced hand at steel treatment can state a furnace temperature very accurately from its appearance and luminosity.

Faint red heat = about 900° F.
Dull red heat = about 1,150° F.
Cherry red heat = about 1,600° F.
Orange heat = 1,990° F.
White heat = 2,350° F.
Intense white heat = 2,700° F.

The appearances indicated above must be judged in the dark.

In measuring temperatures higher than 900°, such as may be found at positions A and B, the following melting points of metals may be of use, viz.—

Zinc melts at 785° F.
Antimony melts at 1,165° F.
Aluminium melts at 1,215° F.

By suspending a strip or wire of each of these metals in the path of the hot gases, some sort of an approximation of the temperatures existing may be obtained by observing which of the metals are fused.

Having now described the apparatus for analysis of flue gases and measurement of temperature and draught, the practical application of these tests will receive attention. In the chart (Fig. 51) three curves are shown—

Curve I of temperature in $\frac{°F.}{100}$

" II of CO_2 in percentage volume.

" III of the draught in inches W.G. × 10.

The various positions at which tests are taken are indicated as ordinates, spaced proportionately to their relative positions in a Lancashire boiler, and lettered to correspond with Figs. 46 and 47.

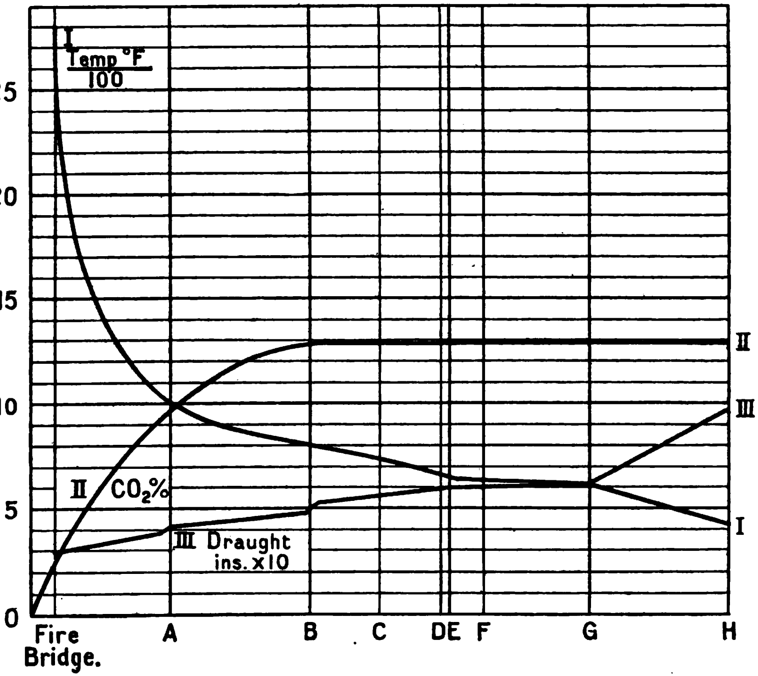


FIG. 51.—Chart of CO_2, Temperature and Draught.

The curves plotted in the chart indicate the various readings that should be obtained on a Lancashire boiler working at a thermal efficiency (see Chapter XIII) of about 80%; or, after allowing for loss in ashes, radiation, moisture and conduction, about 75% efficiency, exclusive of the economiser.

The efficiency indicated is exceptionally high, and can only be obtained under perfect conditions of firing, air regulation and cleanliness of plates and flues, together with complete air tightness of external brickwork and settings, and gas tightness of the internal setting blocks and division walls.

In short, the chart may be compared to the indicator diagram of an engine cylinder; and by keeping all flue tests in a similar form to that shown, any irregularity may be detected immediately and its cause determined with the greatest ease.

Instead of using a separate draught gauge, this instrument may be conveniently attached to the side of the case of the Orsat and permanently connected with the inlet pipe of that apparatus.

If a CO_2 indicator is to be used instead of an Orsat, a permanent set of pipes may be installed, with some such convenient method of readily testing at various points as will be found in the next chapter.

Also by having several electric pyrometer elements in position, each connected through a suitable switch to a single indicator, all readings can be taken practically simultaneously.

Referring again to the "indicator" chart (Fig. 51), we will now describe how the various causes of loss will affect the contours of the different curves (p. 76).

Testing-point C is provided to localise position of air leakage and faulty seating blocks.

A similar curve can be applied to water-tube boilers, the points being lettered in Fig. 47 to correspond with Fig. 46.

The methods of testing and examination of boiler and economiser walls and settings will be dealt with in Chapter XV, with directions as to dealing with defects.

TABLE II.—ANALYSIS OF TEST RESULTS.

Cause of inefficiency.	Curve I.	Curve II.	Curve III.
Forcing of boilers beyond economical capacity	High throughout.	Low at A. " B. Normal at D.	*Induced and natural draught*, high throughout. *Forced draughts*, low throughout.
Over-heavy firing beyond air capacity . .	A low. B & D possibly high.	Low throughout. Excess CO. Smoke.	High throughout.
Thin fires and grate bare in places . .	Low throughout.	Low throughout. Excess O.	Low throughout.
Leaky seating blocks	A & B normal. D high.	A & B normal. D low.	A normal. B & D low.
Short-circuiting at side walls of downtake .	A, B & D normal. E higher than D.	A, B and D normal. E rather low.	Draught not materially affected.
Leakage through back wall of downtake into main flue	A normal. B to E low. F high.	CO_2 not materially affected.	Draught not materially affected, possibly low.
Air leakage into flues	A normal. [1] B normal or low. D low.	A normal. [1] B normal or low. Excess O.	A & B normal. C slightly low.
Air leakage around dampers	E normal. F low.	E normal. F low.	E & F (difference too small to measure).
Dirty plates internally	High throughout, with less fall A to D.	Normal throughout.	Normal throughout.
Dirty flues	Low throughout.	Low throughout. Excess CO.	Low A to C. High D onwards.

[1] Leakage at side flues "normal"; leakage at downtake cover "low."

CHAPTER VII

EQUIPMENT OF BOILER PLANT WITH RECORDING AND INDICATING APPARATUS FOR FLUE GASES.—Tabulation and utility of records.

IN the previous chapter we have seen how, by a combination of tests of the draught, temperature and CO_2 in the flue gases, it is possible to form a very accurate idea of the state of affairs in regard to firing, cleanliness, and all those points vitally affecting the operation of a boiler plant in the matter of efficiency and economy.

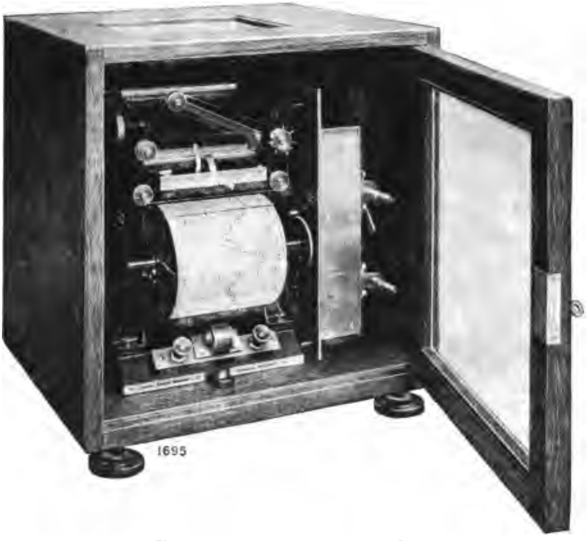


FIG. 52.—Thread Recorder.

Individual tests by hand take considerable time; and if they are to be of any value, these tests must be carried out very frequently.

In order to meet the requirements of continuous working at the very highest possible efficiency (a state of affairs that will pay for the apparatus needed in a very short space of time), recording apparatus permanently fixed in a suitable position in the boiler house and readily accessible is indispensable.

It is not suggested that a separate recorder be provided at every point indicated in Figs. 46 and 47, as this would be a scarcely practicable proposition.

Dealing first with temperature-recording apparatus, as recording pyrometers are somewhat delicate and expensive instruments, their use is only recommended where the size of the plant warrants it, say on batteries of ten Lancashire boilers upwards, or smaller groups of the large water-tube boilers.

The same thermo-couples are used for recorders as for the indicating instruments already described.

The Thread Recorder for thermo-couple pyrometers is shown in Fig. 52, and for boiler work should be of a similar type to that shown, but with a double recorder in one case, each recorder being fitted with a double thread, so that four records are obtained simultaneously on the one chart. This arrangement provides for readings to be taken at four separate points in the flues, two at equally spaced points F, F in the main flue and one each at the economiser inlet and outlet G and H (Fig. 46). Such an installation serves as a general guide to the state of the boilers, with a means of roughly localising defects which will save considerable time when it is desired to investigate any irregularity.

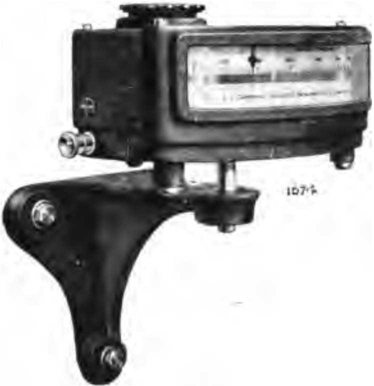


FIG. 53.—Wall Type Indicator.

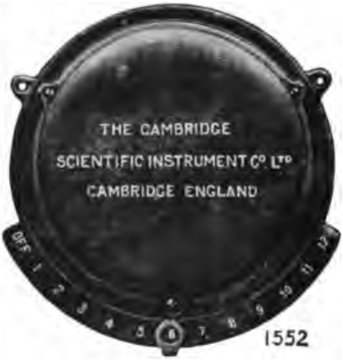


FIG. 54.—Multi-way Switch.

Another arrangement for readily ascertaining the gas temperatures at as many points as may be desired at any moment is the fixed wall type of indicator (Fig. 53), connected through the special multi-way switch (Fig. 54) to the various pyrometer rods.

By means of this instrument it is only necessary to move the switch handle on to the contact corresponding to the position at which it is desired to ascertain the temperature, and an instantaneous reading of this is given upon the scale.

Where pyrometer rods are permanently installed it is as well to have platinum + platinum-rhodium thermo-couples, as these have a much longer life than the "Titan" thermo-couples. Although the "rare-metal" couples are more expensive in first cost they are more economical in the long run, as they are cheaply repaired after failure owing to the high value of the metal recovered from the old elements.

An indicating draught gauge should be connected to the exit of the flues on each boiler to provide a guide to the fireman in regulating his dampers, together with a recording draught gauge connected to point G (Fig. 46) in the main flue.

To obtain the best results each boiler should also have a CO_2 indicator connected at E (Figs. 46 and 47), but probably the room available will prohibit this arrangement except with large boilers. One CO_2 indicator which may be used in a similar manner to the indicating pyrometer, with an arrangement of cocks to replace the multi-way switch of the pyrometer, is a good arrangement, a pipe being led from each of the points to the recorder. The draught gauge pipe must not be used for this purpose, as the vacuum set up by the aspirator of the CO_2 indicator will render the readings of the draught indicator useless.

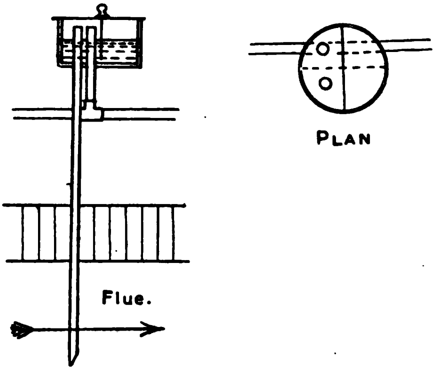


FIG. 55.—Carr Head for CO_2 Recorder Connections.

A CO_2 recorder is now accepted as an indispensable adjunct to a battery of boilers, and is usually connected in the main flue between the boilers and economiser, but an arrangement of pipes and liquid valves is very useful when it is required to take a continuous record of any boiler in a group. Plug cocks are not recommended for flue gas connections except where constantly in use, such as for the CO_2 indicator installation described above.

A liquid valve (or "Carr" head) is shown in Fig. 55 with the method of connecting and disconnecting the CO_2 recorder with the flue. As will be seen, a vertical pipe A leads down from the valve into the flue B, and another connection C is taken from the valve on to the common horizontal main D. The lid of the valve E which fits into the bottom F of the valve dips into the oil G, which acts as an air and a gas seal. This lid is divided diametrically by a gas-tight partition H. To connect the recorder to the flue the lid is so placed that the partition H encloses the two pipe openings A and C in one chamber. By lifting the lid and replacing it with H between the two pipes the recorder is disconnected. The pipes are of iron and the valves themselves of sheet brass.

All the recording and indicating instruments (excepting the independent draught indicators) should be housed in a suitable roomy cabin in the boiler-room, together with the recording thermometers, etc., to be described later in this work.

The independent draught indicators should be mounted on the boiler fronts. Thus from one central point the engineer in charge, foreman or stoker can ascertain in a few moments the conditions obtaining over practically the whole plant, with sufficient indication as to where to make a more detailed examination with portable instruments when all is not in correct order.

Pyrometers in themselves are very accurate instruments, but draught gauges and CO_2 recorders and indicators should be checked at frequent and regular intervals by means of the U-tube gauge and Orsat apparatus respectively, and adjustments made accordingly where required.

All pyrometer readings where an indicator (as distinct from a *recorder*) is used and also draught and CO_2 indicator readings should be carefully logged (upon a suitable daily log sheet) at regular intervals by the leading or foreman stoker, and when this is done by a reliable and conscientious man very valuable data will be obtained, upon which may be based any future steps towards better economy.

CHAPTER VIII

FEED WATER.—Sources of supply—Hardness and impurities—Acidity and alkalinity, how tested and dealt with—Boiler fluids—Water softeners and treatment plant—Protective paints, etc.—Losses due to scale in boilers.

THE ideal feed water for boiler use is pure distilled water which contains no oxygen in solution.

In Nature the nearest approach to this ideal is rain water, which, however, in its passage through the air dissolves a considerable amount of oxygen, which upon the water being heated is liberated in its pure form, and exerts a powerful corrosive effect or rusting upon metallic surfaces, particularly iron.

Rain water that is collected in populous towns is usually of an acid nature, owing to the sulphur oxides from domestic and factory chimney gases forming sulphurous and sulphuric acids with the water.

It may be stated forthwith that in practice no water except the hot-well return from turbine condensing plant, heating apparatus, traps and drains is suitable for use direct into boilers without some form of previous treatment, varying in extent according to the nature and quantity of impurities (solid or gaseous) that are present.

Feed water drawn from rivers and streams varies in its impurities according to the source from which it takes its rise, together with the nature of the soil, vegetation and districts through which it may pass before being drawn upon for feed purposes.

Old mine shafts are often used as a source of feed water, the result being in most cases that a quantity of CO_2 is held in solution, which in this state has corrosive action upon iron pipes and boiler plates owing to the acid nature of this solution.

Wells, like rivers, vary very greatly in impurity from similar causes, and in addition water from wells may be impregnated with carbon dioxide in solution.

The impurities in water which need to be removed before it is suitable for boiler feed are generally classified as under :—

1. Suspended Matter.
2. Temporary Hardness.
3. Permanent Hardness.
4. Free Acid.
5. Oil and Grease.

1. *Suspended Matter* may be mud and other insoluble substances in a finely divided form, which can be removed by settlement or sedimentation and filtration.

After heavy rains river waters usually hold a very considerable amount of solid matter suspended, whilst in dry weather the water may be quite clear or comparatively so.

The substances used for filtration are coke breeze; varying sizes of gravel and shingle; sand and wood wool.

For large volumes of water the coke breeze and shingle filters are a practical means of removal of the major portion of the suspended impurities, wood wool being used for final clarification before treatment for—

2. *Temporary Hardness.*—When CO_2 is dissolved in water it forms an acid solution which readily absorbs chalk and limestone. On boiling such water the CO_2 is driven off and the chalk, etc., is precipitated as an insoluble powder, which may be filtered off by a wood wool filter. Lime water also precipitates these carbonates.

This is the action of all exhaust-steam heater-softeners, the water being divided into sprays or fine streams through which the exhaust steam passes, and in doing so raises the water to boiling-point, the chalk being precipitated and a large portion of the heat of the steam being recovered which would otherwise be lost. Where boiling is impracticable lime will remove temporary hardness, filtration afterwards being necessary.

3. *Permanent Hardness.*—Most soluble salts are not precipitated by boiling, and consequently cannot be filtered out of the water. At the high temperatures and pressures obtaining in boilers some of these salts become acid and attack the metal plates; others are changed to insoluble scale-forming compounds. The reactions are probably very complicated, and vary with temperatures, pressures and nature of the impurities in the water. As a rule these salts do not harden until dried on the boiler plates after the boiler is emptied and is still hot. Soda ash used as described hereinafter tends to keep this scale soft and in such a condition that it may be largely removed by blowing down.

The " Permutit " system also effectively deals with permanent hardness, and so purifies the water that the heat lost in blowing down is obviated, owing to the total absence of impurities after treatment.

" Permutit " is the name given by the United Water Softeners, Ltd., to a series of compounds known to chemists as " zeolytes." These compounds have the property of absorbing the scale-forming salts in water, and when saturated or " spent " do not require renewal. All that is necessary is to pass a solution of common salt through the " Permutit " and it becomes perfectly regenerated; the impurities removed from the feed water are carried away dissolved by the action of the salt solution.

The suspended solids require filtering out from the water before being passed through the "Permutit" bed, or a slimy deposit of mud will be formed which will prevent the contact of water with the zeolyte.

A "Permutit" softener is shown in Fig. 56, with suitable gravel or sand filters combined.

4. *Free Acid* is found mostly in rivers which rise in moorland or peaty soil, and is due to organic acids formed through vegetable decomposition. Acid will not be found in waters that pass through chalky or limestone soil, as these neutralise it.

Acid in rivers may also be caused by effluents from factories in industrial towns, such as acid from pickling tanks, chemical works, etc.

Passing such acid water through a filter bed of marble gravel will neutralise the acid, but with the formation of scale-forming calcium compounds which require subsequent treatment for their removal.

As the property of attacking metals is common to all acids, the detrimental effect of this class of impurity in pitting and corrosion of boiler plates cannot be over-emphasised.

The use of an alkali will neutralise any acid, soda ash being chiefly used for this purpose.

5. *Oil and Grease* are a most dangerous impurity to be found in a boiler. Owing to the resistance that a film of oil opposes to the passage of heat, collapses of flue crowns and bursting of water tubes have frequently been caused through the intense overheating that has taken place, sometimes with disastrous and fatal results.

Where the hot-well discharge from condensers working with reciprocating engines or the use of exhaust-steam feed-water heater-softeners is desired, it is quite indispensable that some form of oil eliminator should be used.

By allowing a solution of soda ash, and another of aluminio-ferric, to flow in separate streams into the feed water from which the oil is to be eliminated, a flocculent precipitate of alumina is formed which effectively entraps all the particles of oil suspended in the water, the result being a coagulation of oil and alumina which is easily filtered out through ordinary filter-tank sand beds or a wood wool filter.

In the author's experience a number of Babcock boilers gave endless trouble through bursting and blistering of tubes due to films of oil and consequent overheating. After installation of a simple plant on the lines indicated above all traces of oil were eradicated, and no further trouble has been encountered from this cause.

In the Davis-Perrett system of oil elimination the feed water is passed through a system of troughs through which an electric current is passed by means of a series of metal plates immersed in the water. This causes the oil to separate out and adhere to the plates, from which it is periodically removed.

The alumino-ferric cum soda process has the merit of simplicity, and applied correctly is quite reliable.

SIMPLE METHODS OF TESTING FEED WATER

It is not proposed to describe the complete analysis of feed water in this work, as this is the province of the highly skilled analytical chemist, but to give simple tests to be applied to the feed water before entering the boiler and to samples of water drawn from the boiler itself.

In all cases feed water should be very slightly alkaline (chemically opposite to, and neutralising acid) after treatment and as it is fed into the boiler.

A rough test for free alkali is by dipping into the water a slip of red litmus paper, which is sold in books for this purpose. If the paper is readily changed from red to a blue colour the water is alkaline, and probably too much soda ash is being used for treatment purposes. A more delicate test is required to ascertain more closely and accurately whether the right amount of alkali (soda ash) is being added. For this purpose a solution of phenolphthalein is utilised.

Some of the water to be tested is put into a small white porcelain evaporating dish, and a drop of the phenolphthalein solution is allowed to fall into it. A rosy purple coloration will be produced, varying in depth according to the quantity of alkali present. In the case of neutral (neither acid nor alkaline) or acid water no coloration will be observed.

Correct treatment is indicated when, on applying the above test and on stirring with a clean glass rod, just a faintly visible coloration is observed.

To detect free acid blue litmus paper may be used instead of red, the blue colour being changed to red when acid is present. As the slightest trace of acid has the most destructive effects in the way of active corrosion and pitting upon metal surfaces of pipes and boiler plates, where its presence is suspected water should be tested with methyl-orange solution, which is much more delicate than litmus paper.

Some clean water is placed in an evaporating dish to which a few drops of methyl-orange solution have been added, so as to produce a canary-yellow colour. Add some of the feed water to this, and if any free acid is present the colour will be changed from yellow to pink.

As an acid and an alkali cannot exist in a solution together, the indication of a slight alkalinity as shown by faint coloration with phenolphthalein is a guarantee that acid is not existent in the water.

When it is desired to test water direct from the boiler the sample is obtained from the water-gauge drain cock. The top cock of the gauge is closed and the water service connection is

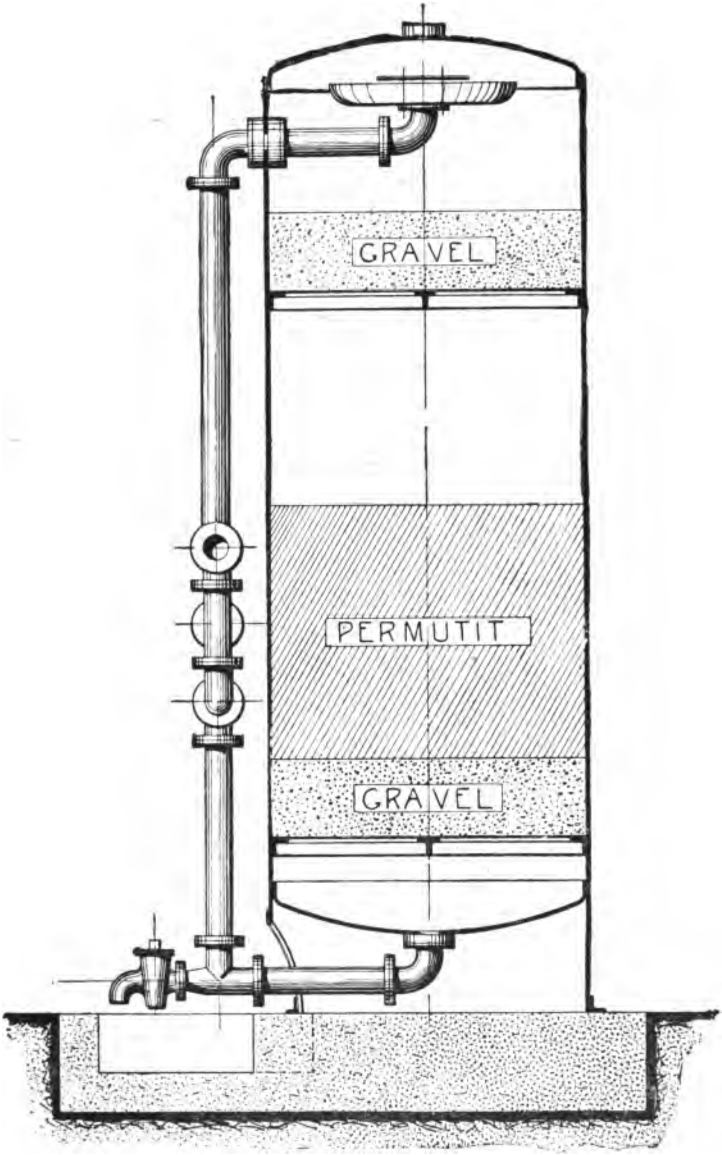


Fig. 56.—Permutit Filter Softener.

blown through for a minute or so to clear away all deposit and stagnant water. Rinse out a tin bottle two or three times with the water to be tested before taking a final sample. Slight alkalinity, as before, is a satisfactory test, as this ensures that the scale formed, if any, is kept soft and can be blown away via the blow-off valve.

Boiler Fluids, etc.

As a rule these are no more than some form of alkali with other substances added which may or may not be of practical utility.

The writer is of opinion that the makers of a large number at least of these "perfect disincrustants" merely trade upon the average engineer's lack of knowledge of chemistry, and by this means fancy prices are obtained for concoctions of quite common and cheap materials.

Water Softeners and Treatment Plant

The Permutit filter already described, apart from its purification of the feed water, has a very valuable feature which should not be lost sight of. As the water, after treatment in a plant of sufficient capacity, is perfectly pure, the boilers do not need to be blown down to remove sediment and excess alkali (a fruitful source of priming).

In the case of a 30 ft. × 8 ft. Lancashire boiler, if 1 in. of water is blown down daily when working at 100 lbs. steam pressure, a weekly loss of heat equivalent to 5¾ cwts. of coal is wasted in the water blown away. Even thus only a small portion of the mud is removed, and therefore this does not in any way replace a supply of perfectly pure water.

As blowing down of boilers is really a rough sort of partial water purification in the boiler itself, some notes on the subject will not be out of place in connection with this subject.

Boilers require blowing down, firstly, to remove suspended and deposited solid matter; secondly, to reduce the quantity of salts in solution which, when sufficiently concentrated, crystallise out on the hot surfaces of the boiler plates; and, thirdly, to keep the excess alkalinity within suitable limits.

With cylindrical boilers blowing down must be done when the boilers are working to obtain the best effect, as the solid matter it is desired to remove is suspended in the water. If the boiler is not working this solid matter lies in the bottom of the shell and on the flue and fire-box crowns, and only that portion immediately surrounding the outlet is removed even with pressure upon the boiler.

As the construction of most water-tube boilers causes the sediment to collect at the lowest point, this type should be blown down when standing under pressure, the blow-down connections being always situated at the lowest point of the circulating system where the sediment collects when the water is not in active circulation.

An excellent appliance for removing solid matter in suspension and floating scum is the Hotchkiss Circulator (A. Ross, Hotchkiss & Co.), which is shown in section in Fig. 57. As its name implies, its primary object is to promote the circulation of the water in a boiler, and for this purpose alone it is a very valuable accessory with marine type cylindrical boilers.

With other boilers than the marine type above referred to, its most valuable feature is the ready way in which floating scum and solid matter is removed from the boiler surface by its circulatory action.

The Hotchkiss circulator works on the syphon principle. A cone-shaped orifice at the working level of the water collects water and scum, which travels up the right-hand pipe (Fig. 57) through the ball-shaped reservoir mounted externally on the top of the boiler. Owing to the greater area of this ball the velocity of the water flow diminishes, causing a large quantity of the impurities to fall to the bottom. On leaving the ball the water is somewhat cooler and therefore of greater density (*i. e.* heavier), and in passing down the leg pipe to the bottom of the boiler causes a continuous circulation by syphonic action. A blow-off pipe is connected with the bottom of the hollow ball, the other end of which is connected through a plug cock at the boiler front to an open end, which discharges into a tundish and thus to waste. The cock should be operated every one and a half to three hours, according to the degree of impurity in the water. As this pipe has an open-ended discharge the cock can be closed immediately the water is seen to blow clear, which thus has a great advantage over blowing down in the ordinary way, for of course the blow-off water is invisible and is therefore excessive in most cases, in order to be sure that all sediment possible is removed.

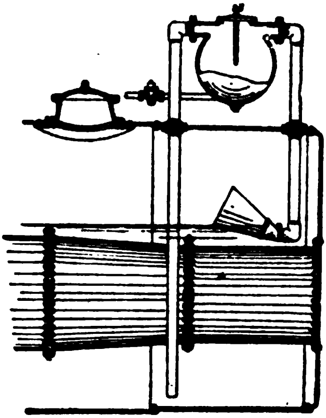


Fig. 57.—Hotchkiss Circulator.

The circulator is started by opening the pet-cock on top of the ball until water is ejected, when the boiler commences to show pressure on the gauge.

As soda ash or any other reagent should never be introduced into feed water in bulk, some form of apparatus is necessary that regulates the supply of chemical strictly in proportion to the rate of flow of the feed water.

If this is not done, and instead the soda is thrown into the feed-water tank by the bucketful at a time, as is very often done, an invariable result is a more or less extensive inequality of distribution.

Some boilers in a group will get excess soda with consequent priming and foaming, resulting in loss of heat in wet steam. The other boilers may have sufficient soda at first, and when the feed tank is denuded of its supply of alkali the remaining water will be untreated.

Where boiling by exhaust steam is not adopted and lime is used instead, these remarks apply equally to the distribution of the lime.

Taking the case of water treatment by the cold process, two types of apparatus may be mentioned, viz. the Paterson and the Lassen and Hjort. Both of these plants use an arrangement of tipping-tanks for measuring the water to be treated, the first-named plant utilising the reciprocating motion produced to operate a pair of cups working in the reagent tank (containing a mixture of lime and soda solution), each cup alternately filling and then emptying into the stream of feed water discharged from the oscillating double tank (or " Osilameter," as it is called by the makers).

The Lassen and Hjort plant also uses a pair of tipping-tanks, which measure the water passed and serve to operate a measuring valve in the bottom of the chemical tank which is fitted alongside.

By adding a counting gear to either of these devices to count the number of oscillations, a means of accurately metering the water by bulk is obtained.

Wherever a supply of exhaust steam is available a " hot process " softener should be installed, as the use of lime and consequent additional filter capacity is avoided, and, more important still, a very large proportion of the heat of the steam is recovered which would otherwise be lost (see Chapter IX following).

The Paterson " hot process " softener uses as a measuring device a tank divided by a V notch weir in which there is a float. The float operates a spindle above by means of a chain. This spindle passes across the top of two tanks, each containing a suitable reagent, one for a solution of soda ash and the other a solution of sulphate of alumina. The spindle operates, by means of pulleys, a needle valve in each reagent tank, the opening of which is proportionate to the flow of water indicated by the height in the V notch of the measuring tank; these valves are operated by the float before mentioned. The temporary hardness in this case is removed by boiling in the heater, and the sediment of carbonates formed is filtered out through a wood wool filter. The water then passes through the weir, being there mixed with the reagents for removal of permanent hardness and oil (from the exhaust steam), the precipitates and coagulations being filtered through a quartz filter before finally passing to the feed pump. In order to maintain the constant head necessary for a properly regulated supply of reagent through the needle valves, the tanks in which they are fitted are kept at a constant level by ordinary ball valves supplied by larger storage and mixing tanks.

PROTECTIVE PAINTS

For feed pipes carrying water before treatment, where such is of a corrosive nature an internal coating of a suitable paint is required.

Graphite paints prepared especially for this purpose are obtainable and are very effective.

Another favourite method of internally protecting water pipes from corrosion is the application of a hard coating of pitch by means of Dr. Angus Smith's composition, which consists of a mixture of coal tar, tallow, quicklime, resin and coal naphtha in suitable proportions. The mixture is heated in a tank and the pipes immersed in the hot mixture.

It should also be noted that cast-iron pipes resist acid corrosion better than wrought-iron ones, and also common grey cast iron is to be preferred to the best Yorkshire iron.

For preventing the adhesion of scale to the surfaces of boiler plates, some enamels, such as "Skaylene," have proved very successful. These paints give a smooth, hard surface from which the scale falls away in sheets very easily. The coating requires renewal after every three cleanings, and the plates must be thoroughly wire-brushed before application of the paint. This class of paint only reduces the inconvenience and difficulty of removing scale which should be prevented from being formed by previous treatment.

Apart from the cost of cleaning boilers, its property as a non-conductor of heat is the most important objection to the presence of scale.

Owing to the very high resistance scale offers to the passage of heat (and its heaviest formation is always upon the hottest surface), failures of water tubes and burning of plates are very frequent results of its presence.

From the same cause, the waste of fuel due to reduced efficiency of the boilers can reach a very serious amount, which varies with the thickness of the deposit and the nature of its composition.

On an average—

$\frac{1}{16}$ inch	of scale	reduces	efficiency	10 %
$\frac{1}{8}$,,	,,	,,	,,	20 %
$\frac{1}{4}$,,	,,	,,	,,	34 %
$\frac{1}{2}$,,	,,	,,	,,	80 %

The importance of keeping the heating surfaces clean is at once apparent from the above figures.

With water-tube and multi-tubular boilers the loss is considerably greater than shown in the above table, whereas with plain cylindrical boilers, such as Lancashire and Cornish types, the loss is somewhat less.

A battery of boilers burning 100 tons of coal per week, with an average of $\frac{1}{8}$ in. of scale, would only use 95 tons in the same period if the average were reduced to $\frac{1}{16}$ in., a saving of 250 tons of coal per year of 50 weeks, or £312 per annum with coal at 25*s*. per ton.

CHAPTER IX

FEED-WATER HEATING.—Heat of water—Exhaust steam heaters—Live steam heaters—Economisers—National circulator—Utility of hot feed—Hot-well return from heating apparatus, condensing plant and steam-pipe drains—Thermometers, indicating and recording.

To obtain the total heat in B Th U. in 1 lb. of water, subtract 32 from the observed temperature in ° F., and the remainder will give the heat in 1 lb. of water at this temperature with very close accuracy. Actually the figure obtained will be very slightly low.

This rule only applies at atmospheric pressure and up to a temperature of 212° F.

For temperatures above 212° F. (*i. e.* boiling-point) it is not possible to ascertain the heat in any particular weight of water, as this depends upon the pressure within the vessel containing the water and the amount of "latent heat" (see Chapter XI) that has been absorbed by the water.

As each degree F. represents 1 B.Th U. per lb. of water, the "specific heat" of water at atmospheric pressure is approximately 1·0.

TABLE III.—WEIGHT OF WATER PER GALLON.

Temp. °F.	Weight per gall.	Temp. °F.	Weight per gall.	Temp. °F.	Weight per gall.
32	10·01 lbs.	80	9·98 lbs.	130	9·87 lbs.
40	10·01 ,,	90	9·96 ,,	140	9·84 ,,
50	10·01 ,,	100	9·95 ,,	160	9·78 ,,
60	10·00 ,,	110	9·93 ,,	180	9·71 ,,
70	9·99 ,,	120	9·90 ,,	200	9·63 ,,

It is obvious that by heating the feed water from some independent source, the heat of which would otherwise be lost, a very considerable saving of fuel may be obtained. The heat thus conveniently available is usually the exhaust steam from engines and the heat of flue gases from boilers and furnaces. In addition, the hot-well discharge from condensing engines is usually of a fairly high temperature, likewise the drainage from heating apparatus and steam mains.

EXHAUST STEAM FEED HEATING

There are two general types of heaters using exhaust steam, viz. the tubular and the open forms. Where no extraction of oil is carried out the tubular form of heater is used, as the steam and water do not come into actual contact, so the danger of oil in the boilers is not existent. A sketch of such a heater is seen in Fig. 58. The water should pass outside the tubes, as shown by the U-shaped indicating line, and the steam should pass through the tubes in the opposite direction on the " contra flow " principle.

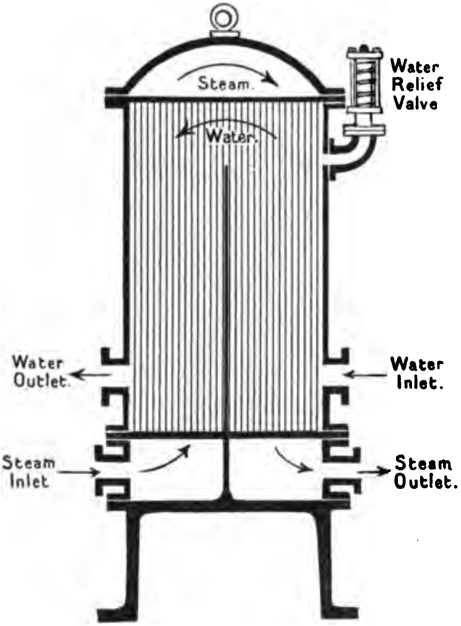


FIG. 58.—Tubular Heater.

In connection with tubular heaters it must be borne in mind that the exhaust steam will deposit a film of oil on the surfaces of the tubes through which it passes, and, owing to the non-conducting property of the oil, already noted elsewhere, will not allow a tubular heater to work at a very high efficiency. Owing to its being made in very small sizes for pump exhaust, etc., the tubular heater is sometimes convenient, but this form should never be used where it is possible to instal an open type heater where the exhaust steam and feed water come in intimate contact with each other.

A form of tubular heater giving a very efficient heating effect is that of Messrs. Royles, Ltd., which uses Row's indented tube, and is shown in Fig. 59.

As the presence of oil in feed water can be satisfactorily and readily dealt with by means of sulphate of alumina, filtering and neutralising with soda, the usual objections urged against the open or contact form of heater are really groundless.

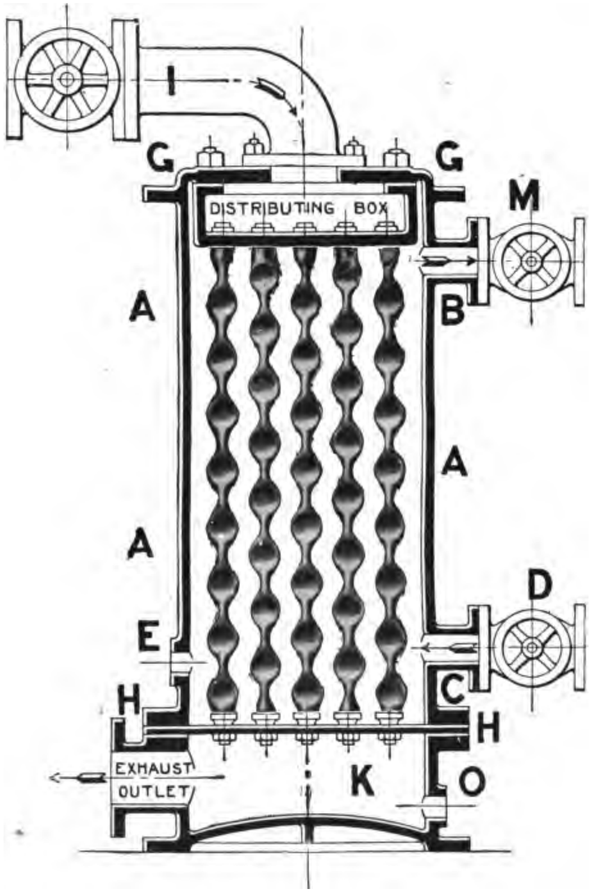


FIG. 59.—Row's Tubular Heater.

All these heaters consist of some means of spraying the water, or else by causing it to flow downwards over a series of staggered and perforated baffles, through which the steam passes upwards, heating the water in its passage before finally being discharged to atmosphere. The water is boiled by the heat of the steam, and then passes through a wood wool filter, which removes the sediment caused by the precipitation of the temporary hardness, or magnesium and calcium carbonates.

By final treatment with solutions of soda ash and sulphate of alumina and filtering a perfectly oil-free and slightly alkaline feed water is delivered to the feed pumps.

LIVE STEAM HEATERS

These are a speciality of Messrs. Royles, Ltd., and employ Row's tubes in their construction. They are similar in construction (but necessarily made of heavier sections of metal) than the exhaust steam pattern by the same firm.

The chief utility of live steam heaters is to provide a hot feed to economisers, or, should these not be used or out of action, direct to boilers, so that the unequal strain associated with cold feed are avoided. It is also claimed that an economy of up to 8 % is obtained by live steam feed heating, but this is a very debatable statement, as it amounts to saying that by taking heat out of the boiler in steam and returning it again by way of the feed water a gain of 8 % in efficiency is obtained.

The author is unable to find any records of tests supporting this claim to added efficiency, and rather fancies that, should such tests have been taken, the steam used to heat the feed water has been calculated as water evaporated instead of being *subtracted* from the total water passed into the boiler.

Should this economy be actually as stated (*i. e.* 8 %), the same argument would apply to the use of injectors for boiler feed, but no claims as to additional economy appear to have been made by their use.

The use of hot feed into a boiler must necessarily reduce the thermal efficiency of the boiler as a unit in a complete plant (see Chapter XIII on "Transference of Heat"), owing to the reduced difference in temperature between the furnace gases and the water within the boiler.

The *economy* in fuel is, of course, greater; therefore the use of heat for feed water, instead of wasting it, will increase the efficiency of the whole plant as a producer of power from the coal.

ECONOMISERS

This widely used device for utilising the heat of boiler and furnace exit gases consists of a number of cast-iron pipes built into the boiler flue, through which the water is usually pumped at boiler pressure before passing into the boilers themselves. The pipes are made up into sections connected by horizontal inlet and outlet headers at the bottom and top respectively. Any multiple of 4 of these sections are connected together by branch pipes at the bottom and top, as a common inlet and outlet for each group of sections. The sections are arranged transversely in the flue, the branch pipes thus running longitudinally. The water passes into the economiser at the end nearer the chimney by the bottom branch pipe and out at the end nearest the boilers by the top branch pipe, these usually being referred to as the "cold end" and "hot end" respectively.

Soot being a very poor conductor of heat, an arrangement of scrapers, worked from gearing mounted on the top of the economiser, is provided to keep the external surfaces of the pipes clean.

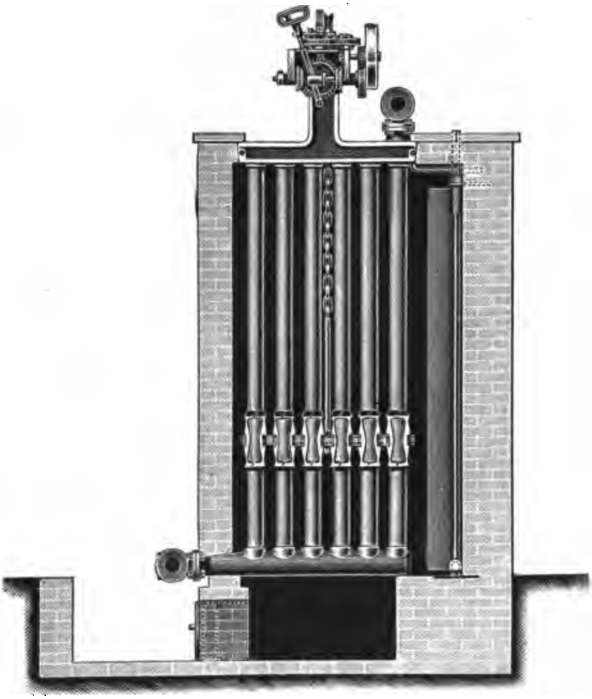


FIG. 60.—Green's Economiser.

The water must not enter the economiser at a lower temperature than 110° F., or condensation of moisture with formation of sulphuric acid or sulphurous acid will take place, causing rapid destructive corrosion of the lower ends of the pipes, especially at the cold end.

A cross section of an economiser by Messrs. E. Green & Son, Ltd. of Wakefield is shown in Fig. 60.

MANAGEMENT OF ECONOMISERS

Messrs. Babcock & Willcox also fit an economiser, when ordered, directly above their marine type boilers, as shown in Fig. 91 (p. 141), which, as will be noted, consists of a number of sections of tubes similarly constructed and arranged as are the water tubes of the boiler itself. The tubes are inclined, and the cold water enters at the lowest extremity by a header box, and leaves by a similar box at the highest point. The gases are made to pass through the nest of tubes three times by means of fire-brick baffles, as can be clearly traced by the arrows.

CARE OF ECONOMISERS

To obtain the best results from economisers, like all other appliances they require a certain amount of care and attention.

All dampness must be avoided in the brickwork settings and supports, as damp brickwork is a very frequent cause of corrosion of metal with which it comes into contact.

Care must be taken that the water does not enter the economiser at a lower temperature than 110° F., as before mentioned, as this not only causes serious corrosion, but the moisture also cakes the soot upon the pipes, thus preventing the scrapers from making their full downward travel.

The scrapers must be kept continuously working, as soot is a very bad conductor of heat, and a thin layer of this deposit will greatly reduce the efficiency of the economiser.

In most economisers of the Green's type deflector plates or narrow swing dampers are fitted to close the space left between the pipes and the flue wall, this space being provided for access to the pipes for cleaning and examination. The square head of the deflector spindle, which projects through the top of the flue, should be provided with a square plate with a hole in the centre to fit over the spindle. A recess is cut in the flue cover into which this plate fits easily, the plate holding the deflector open or closed as required by dropping it over the spindle and into its recess. It is not at all an infrequent occurrence to find these deflectors quite unprovided with any means of holding them in position, and, as a consequence, they are nearly always more or less open, which results in a large portion of the gases being by-passed direct to the stack without travelling through the economiser at all, thus reducing the heat recovery to a very serious extent.

It is important that the feed water should be fed steadily and not in irregular rushes through the economiser. If this is not done, not only are considerable varying strains set up, but the probability is that between the intervals of heavy feeding the temperature of the water within the economiser will reach that corresponding to the working pressure (see Steam Tables in Appendix) and steam is generated, causing hammer in the pipes and blowing off at the economiser safety valve.

It must be remembered that when the water level is kept steady in the boiler under all conditions of demand it is necessary to regulate the fires and dampers to keep the steam pressure. It will thus be seen that the flow of gases and feed water will be approximately proportional under all conditions with a constant difference of temperature in the economiser.

The practice of partially by-passing the gases is obviously a most wasteful method of dealing with excess heat; the proper way, as described, is to regulate the fires and water together.

Economisers should be blown down for at least a few seconds daily, and more frequently when the feed water is of a sedimentary nature.

In connection with scrapers it should be noted that the chain pulleys must not be allowed to get greasy, or the chains will slip in the groove, with resulting loss of travel. Also see that the scraper rods rise equally above the top of the economiser at the end of each stroke. When the chains become stretched remove one or two links as may be found necessary.

ACCESSORIES FOR USE WITH ECONOMISERS

One method of raising the inlet water temperature is to connect a pipe of about ¾ in. bore from the outlet header to the feed-pump suction inlet, regulation of the temperature being by hand with a wheel valve.

Feeding by injector will also meet the difficulty, but as this will probably raise the temperature to about 180° to 200° F., a large loss of efficiency is the result, owing to the reduced temperature difference between gases and water. Other disadvantages of injectors are mentioned in the next chapter.

THE NATIONAL PATENT ECONOMISER CIRCULATOR

This device has been introduced by the National Boiler and General Insurance Company to meet the requirements of economisers in regard to inlet water temperature. It consists (as seen in section in Fig. 61) of practically a water-jet ejector. The main flow of cold feed water passes through the renewable nozzle, a certain quantity of hot water being drawn into it by injector action from the outlet header of the economiser. The greater the quantity of feed water that is pumped through, the greater will be the quantity of hot water injected, these quantities being in direct proportion. A valve is introduced into the hot-water feed pipe, and with fairly steady feeding, after once regulating, the temperature can be kept to 110° F. If the variation in feed is very large the valve in question will probably need adjusting from time to time.

With reciprocating feed pumps the hot-water inlet of the

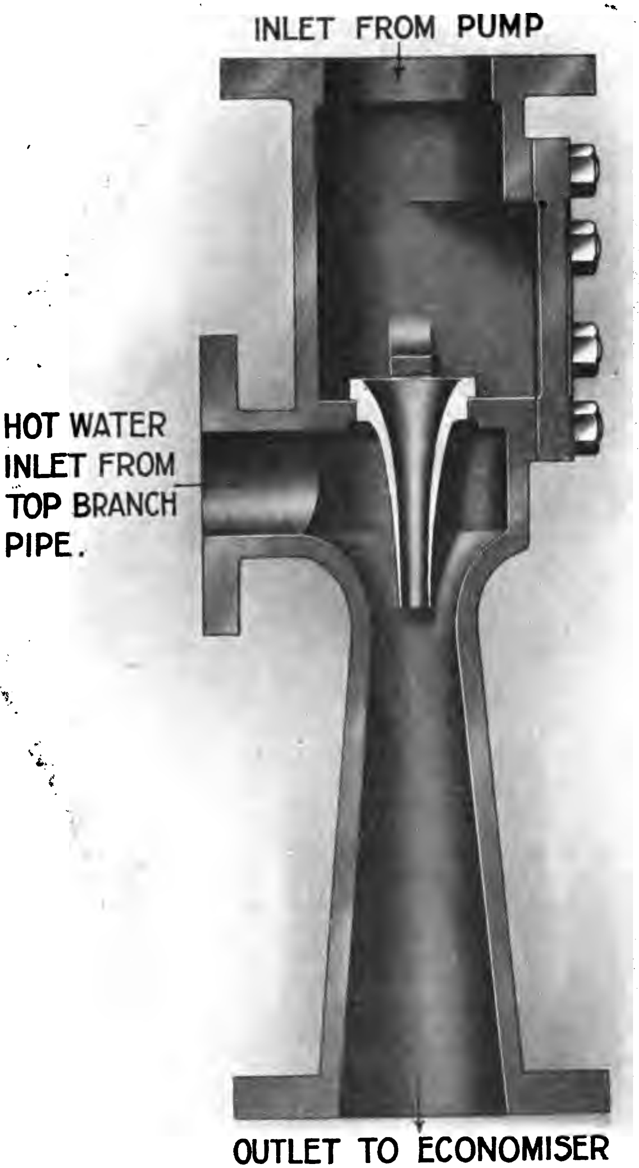


FIG. 61.—National Patent Economiser Circulator.

circulator must be at least 1 ft. above the economiser outlet header, or hammering is very likely to take place. The pipe for the hot service is connected to a special diaphragm T-piece between the safety valve and header, and must rise continuously from this T-piece to the hot-water inlet.

With a steady pressure such as that from a rotary or turbine feed pump the National Circulator appears to work quite satisfactorily in any position relatively to the economiser outlet.

SCRAPER CHAIN-HOLE SEALS

The chains for operating the scrapers having to pass through holes between the top boxes of the sections of pipes, a loss of temperature, apart from that due to heat absorption by the water, is bound to take place through air indraught, unless some means is adopted to prevent this.

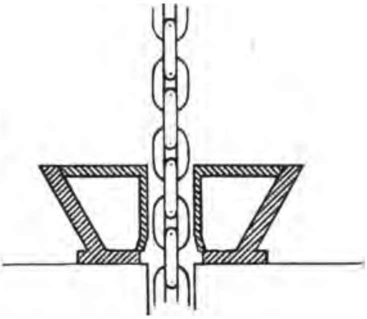


Fig. 62.—Haywood Air-Tight Chain Seal.

A simple and effective device for minimising this loss is the chain-seal supplied by the Haywood Air-tight Damper Company. As seen in section in Fig. 62, it consists of a rectangular tundish-shaped receptacle in which are situated a pair of loose sliding blocks, which are so formed that they provide a cross-shaped opening for the chain to pass through. When the scraper rod rises these blocks part and lift a little way, allowing the rod to pass between them. When the rod lowers again the blocks slip back again around the chain. These seals are not fixed to the economiser top, but are free to move so they alter their position to conform to any irregularity in the shape or twist in the chain.

SIZES OF ECONOMISERS

If the evaporation of the boiler plant per hour is known the size of economiser in number of pipes is found by dividing the number of gallons per hour evaporated by 6¼, the correct quantity of water at any moment being one hour's supply, and each standard 9 ft. pipe contains 6¼ gallons of water.

Owing to the scraper gearing requiring an even number of pipes per section, and the sections to be in multiples of 4, the nearest suitable size of economiser can be easily determined. Sections are made up of 4, 6, 8, 10 and 12 pipes wide.

For the purpose of gauging corrosion, it should be noted that the external diameter of a new pipe is $4\frac{9}{16}$ in.

ADVANTAGES OF FEED HEATING

Where heat for raising the temperature of boiler feed is obtained from some outside source, the advantage of utilising such "waste" heat is obvious. The actual effect upon the coal consumption will be seen by reference to Table IV, Fig. 63, which shows the saving in percentage of fuel consumption at various initial and final temperatures with steam pressure of 100 lbs. per square inch by gauge.

TABLE IV.

Initial Temp. of Water ° F.	Final Temperature of Feed Water ° F.													
	100	110	120	130	140	150	160	180	200	220	240	260	280	300
40	5·05	5·89	6·73	7·58	8·45	9·26	10·1	11·8	13·5	15·1	16·8	18·5	20·2	21·9
45	4·63	5·47	6·31	7·16	8·00	8·85	9·68	11·3	13·0	14·7	16·4	18·1	19·8	21·5
50	4·21	5·05	5·89	6·73	7·58	8·45	9·26	10·9	12·6	14·3	16·0	17·7	19·4	21·1
55	3·79	4·63	5·47	6·31	7·16	8·00	8·85	10·5	12·2	13·8	15·6	17·2	18·9	20·6
60	3·37	4·21	5·05	5·89	6·73	7·58	8·45	10·1	11·8	13·5	15·1	16·8	18·5	20·2
65	2·95	3·79	4·63	5·47	6·31	7·16	8·00	9·68	11·3	13·0	14·7	16·4	18·1	19·8
70	2·53	3·37	4·21	5·05	5·89	6·73	7·58	9·26	10·9	12·6	14·3	16·0	17·7	19·4
75	2·11	2·95	3·79	4·63	5·47	6·31	7·16	8·85	10·5	12·2	13·8	15·6	17·2	18·9
80	1·68	2·53	3·37	4·21	5·05	5·89	6·73	8·45	10·1	11·8	13·5	15·1	16·8	18·5
85	1·26	2·11	2·95	3·79	4·63	5·47	6·31	8·00	9·68	11·3	13·0	14·7	16·4	18·1
90	0·84	1·68	2·53	3·37	4·21	5·05	5·89	7·58	9·26	10·9	12·6	14·3	16·0	17·7
95	0·42	1·26	2·11	2·95	3·79	4·63	5·47	7·16	8·85	10·5	12·2	13·8	15·6	17·2
100	0	0·84	1·68	2·53	3·37	4·21	5·05	6·73	8·45	10·1	11·8	13·5	15·1	16·8
110	—	0	0·84	1·68	2·53	3·37	4·21	5·89	7·58	9·26	10·9	12·6	14·3	16·0
120	—	—	0	0·84	1·68	2·53	3·37	5·05	6·73	8·45	10·1	11·8	13·5	15·1
130	—	—	—	0	0·84	1·68	2·53	4·21	5·89	7·58	9·26	10·9	12·6	14·3
140	—	—	—	—	0	0·84	1·68	3·37	5·05	6·73	8·45	10·1	11·8	13·5
150	—	—	—	—	—	0	0·84	2·53	4·21	5·89	7·58	9·26	10·9	12·6
160	—	—	—	—	—	—	0	1·68	3·37	5·05	6·73	8·45	10·1	11·8
170	—	—	—	—	—	—	—	0·84	2·53	4·21	5·89	7·58	9·26	10·9
180	—	—	—	—	—	—	—	0	1·68	3·37	5·05	6·73	8·45	10·1
190	—	—	—	—	—	—	—	—	0·84	2·53	4·21	5·89	7·58	9·26
200	—	—	—	—	—	—	—	—	0	1·68	3·37	5·05	6·73	8·45

FIG. 63.—Table showing percentage of fuel saved by heating feed water. Steam pressure 100 lbs. per sq. in. by gauge.

For any other steam pressure than that given the following formula will give the amount of saving obtained by heating the feed water—

$$E = \frac{(W_2 - W_1) \times 100}{S}$$

Where E = Economy of fuel in per cent.
W_1 = Total heat per lb. of cold water (*i.e.* Initial Temp.).
W_2 = ,, ,, ,, hot water (*i.e.* Final Temp.).
S = ,, ,, ,, steam at working pressure.

The various quantities being found by reference to the tables in the Appendix.

Where only a supply of cold water is available it should never be admitted to the boiler in this condition, as severe stresses are set up due to unequal heating. The detrimental effect on economiser pipes has already been dealt with. In boilers this unequal expansion will probably lead to leaky seams and grooving of the plates.

Under circumstances where the water cannot be heated otherwise, feeding of the boilers should be carried out by means of injectors, which in the course of their normal operation heat

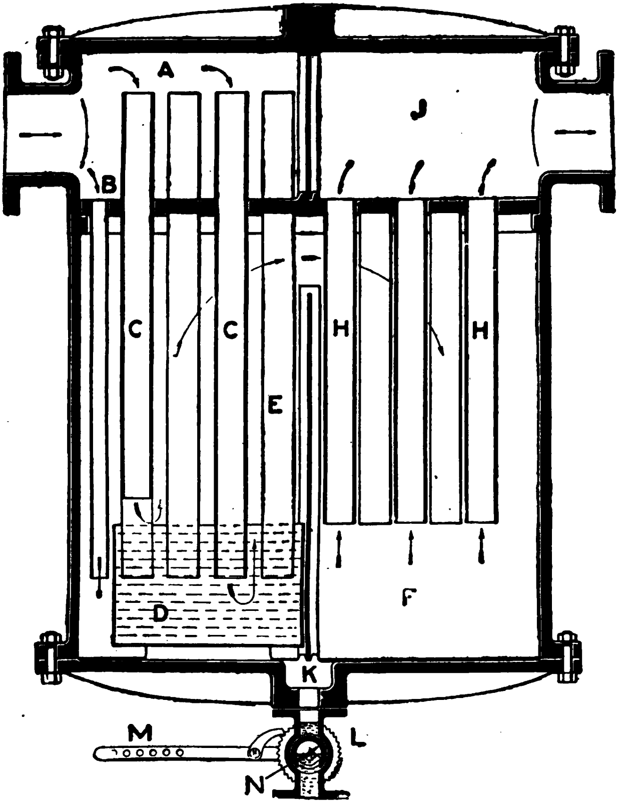


FIG. 64.—Royle's Oil Separator.

the water up to about 200° F. at average working pressures. Injectors should not be used to feed into an economiser, as the efficiency of the plant is reduced thereby, for the heat gained in passing the water through an injector is obtained from the boiler itself, and serves to reduce the amount of heat recovered from the flue gases. A circulator should be installed to maintain economiser inlet temperature.

Heating by live steam is another method of keeping the feed water at a reasonably high temperature for boiler feed, but this also is not economical, as by doing this there is sure to be a loss of heat by radiation from the steam pipe connection.

OTHER SOURCES OF HOT FEED

In most cases it will be found that if all the traps, drains and heating apparatus are arranged to discharge into a common hot well through water-heating nozzles, the temperature of the water will be sufficiently high to deliver direct into the economisers without any additional means of heating, especially if the main supply is the hot-well return from condensing plant, which at 27 inches of vacuum will be in the region of 114° F.

As the hot-well water from the various sources described will be absolutely without hardness it requires no softening treatment, although the condenser hot-well water will require the removal of oil by the usual means of coagulation, etc.

To remove the bulk of the oil in exhaust steam a special oil separator has been introduced by Messrs. Royles, Ltd., and is shown in Fig. 64. It is situated in a suitable position in the run of the exhaust pipe. The steam entering the separator by the inlet branch follows the course of the arrows, whilst the oil and water running along the bottom of the horizontal exhaust pipe is led away by the pipe B, leaving the separator to deal only with the oil actually held in suspension by the steam. The inlet tubes CC, whose total area is considerably greater than that of the exhaust pipe, serve to divide the steam into a number of streams and lead these into the water in the tank D. The steam passes upwards through the water, being washed in transit and freed from the greater part of the oil. As fast as the oil rises to the surface of the water it flows over the edges of the tank, and so away to the drain. The steam then slowly rises and moves among the inlet tubes in contact with the outlet tube. The oil and condensed water flow away through K.

FEED-WATER THERMOMETERS

In common with the other measurements in connection with the operation of boiler plants, the temperature of the feed water requires constant observation.

Thermometers must be provided in the feed water system at the following points.

Boilers without economisers—

- On feed pump delivery.
- At injector water inlet and outlet.

Boilers with economisers—

- At economiser inlet and outlet, and also at circulator cold inlet (where this is installed).

For ordinary intermittent readings, malleable iron pockets are screwed into the pipes or economiser headers where desired, and ordinary mercurial thermometers (with brass-protecting cases fitted) inserted in the pockets. These pockets must be partially filled either with mercury or with oil, but preferably the former.

Where regular readings are to be taken, some form of distance thermometer should be used so that the temperature at the various points may be read at a convenient position in the boiler house.

Such distance thermometers should be housed in a suitable cabin together with the other indicating and recording apparatus described in other chapters dealing with their particular uses. They may be either indicating or recording, but preferably the latter.

Distance thermometers are of two types, viz. mercurial pressure and electrical.

The pressure type of mercurial type consists of a steel bulb screwed into the feed water pipe or header connected by a capillary steel tube with a pressure gauge graduated in degrees of temperature. The bulb, capillary tube and gauge tube is filled with mercury, which expands when subjected to a rise of temperature, the resulting pressure being indicated on the gauge or recorder chart. Mercurial thermometers of this type can be provided with capillary steel tubing up to 75 ft. in length, this, therefore, being the maximum permissible distance of the thermometer gauge from its bulb.

There is no limit to the distance at which an electrical thermometer indicator may be situated from its "bulb." These instruments depend for their operation on the fact that the resistance offered to the passage of an electric current by a wire varies with the temperature. The indicator moves in conformity with the variations of current caused by changes of temperature of the bulb. The bulb contains a coil of wire, and a very small current at steady pressure (voltage) is passed through this and the indicator by means of an accumulator.

To obtain the efficiency of the plant throughout the period of working or at any desired moment the recording thermometer, or "thermograph," is indispensable, the general utility of continuous records on charts of boiler plant performance having been described in connection with the use of pyrometers.

Dirty economisers, either or both inside and out, will show insufficient difference in temperature between inlet and outlet temperatures of water and gases. When the flow of water is above the normal the increase of water temperature will be small and the reduction in gas temperature will be comparatively great, the opposite being the effect with water-flow less than normal.

CHAPTER X

FEED PUMPS, INJECTORS AND METERS.—Types and characteristics of feed pumps—Injectors—Turbine pumps—Automatic boiler feed-water regulators—Typical water meters and flow recorders—Tipping-tanks—Feed mains and tanks.

FEED PUMPS

PLUNGER type feed pumps are either steam or electrically driven. In the latter case they are almost always of the double or single acting three-throw class. The steam-driven pumps used in up-to-date plants are usually vertical with double-acting water cylinders, and either single expansion or compound steam cylinders. Horizontal pumps are also used, principally in the smaller capacities, prominent among these being the Worthington Duplex; the larger sizes are well represented by the compound duplex "Odesse" pump of Messrs. Lee, Howe & Co. Good examples of vertical single expansion pumps are the "Weir" and the "Anthony" pumps.

The "Pearn" type of pump is really a combination of the three-throw and direct acting pumps, although it may be, and is, constructed in one, two or three lines. It consists of ordinary steam cylinders and D slide valves, connected by rods and cranks to a flywheel shaft which serves to give a steady turning moment. The reciprocating movement of the piston rods is carried to the water cylinders beneath by an iron casting, shaped like the outline of an inverted kite so as to clear the throw of the revolving crank.

The pump is very cumbersome and occupies considerable space compared with its output, and is now being supplanted almost entirely by more modern forms in which the difficulty of "kicking" at the end of each stroke has been overcome by perfected design of the valve gears.

VERTICAL SINGLE EXPANSION PUMPS

The Weir pump (Fig. 65) is probably the best-known example of this class. As with all reciprocating boiler feed pumps, its main point of interest is the steam valve gear. This consists principally of two parts: (1) a main valve for distributing steam to the cylinders, and (2) an auxiliary valve for distributing steam to operate the main valve. The auxiliary valve works vertically upon the back of the main valve, which has a horizontal motion. The auxiliary valve receives its motion direct from a lever operated by a cross-head on the main pump rod; this admits steam to either end of the main valve, according to the position of the pump piston. The main valve is thrown first to one side and then to the other, uncovering and closing the parts into the cylinder alternately. The auxiliary valve closes the ports leading to the cylinder at about three-quarters stroke, and the remainder of the stroke is completed by the expansion of the steam shut in the cylinders.

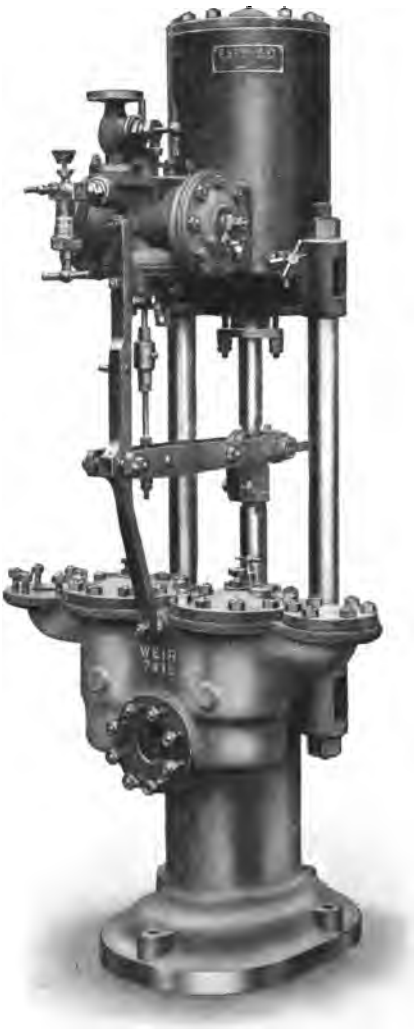


Fig. 65.—Weir Feed Pump.

On the outside at each end of the steam chest a lever will be found which may be secured in any required position by a stud and wing-nut. These levers regulate by-passes to each end of the cylinder and provide a means of allowing a small extra supply of steam at full pressure to be admitted to the cylinder to meet special conditions such as starting the pumps with the cylinders cold. The pump should be started with these levers in the open position (marked "O" on the circular cover casting), and they should be gradually moved towards mark "S" until the pump will complete its stroke with a "soft" or cushioned finish. It is very important that these levers are carefully adjusted, as if the

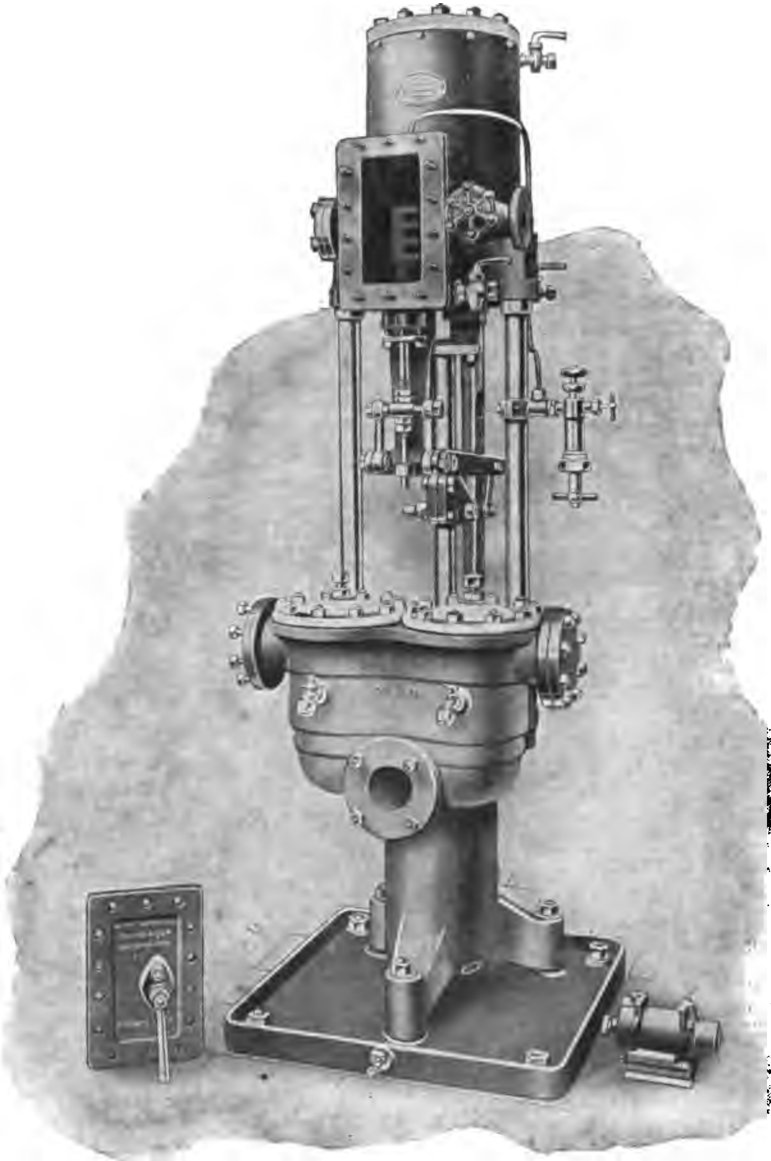


Fig. 66.—Anthony Feed Pump.

by-pass ports are kept open too long there will be a hard finish to each stroke or "kick" which causes heavy vibration in the feed pipes, and will also damage the valves in the water chamber. The pump will also be uneconomical if this point is not attended to, by taking an unnecessary amount of steam to drive it.

The "Anthony" pump is also a single-acting vertical pump supplied by Messrs. Robert Warner & Co., and is quite a recent introduction. This pump is distinguished by the very simple valve gear, small working parts and extreme accessibility. It is seen in Fig. 66 with the steam chest cover taken off and the whole of the valve removed and placed at the right-hand side. These pumps are supplied in capacities varying from 420 to 8,820 gallons of water per hour.

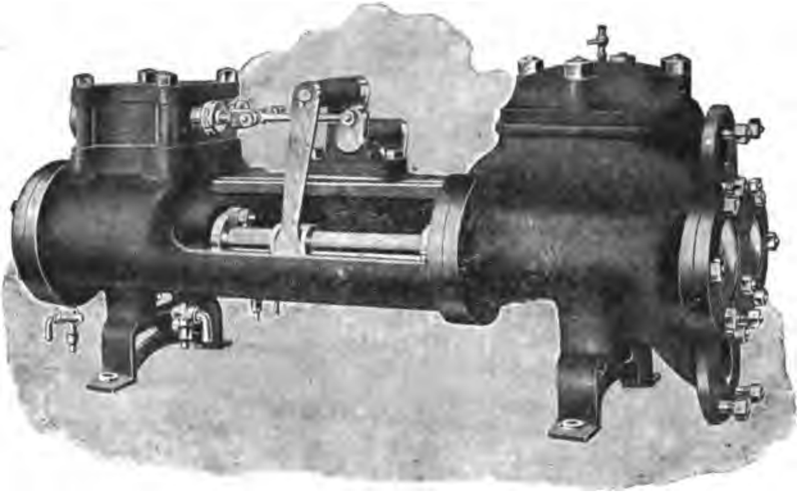


Fig. 67.—Worthington Duplex Feed Pump.

The "Hall" compound vertical pump has a valve gear composed of two piston valves, one (the auxiliary valve) worked direct from the pump-rod lever and the main valve being loose and operated by steam from the auxiliary valve.

HORIZONTAL PUMPS

The majority of these pumps at present in use are of the duplex type, consisting of a pair of pumps, the rod of one operating the valve gear of the other and vice versa.

For small pumps the Worthington Duplex may be taken as typical, and one of these is illustrated in Fig. 67. The valve gear is a simple D slide valve operated by a spindle deriving its motion from the opposite line.

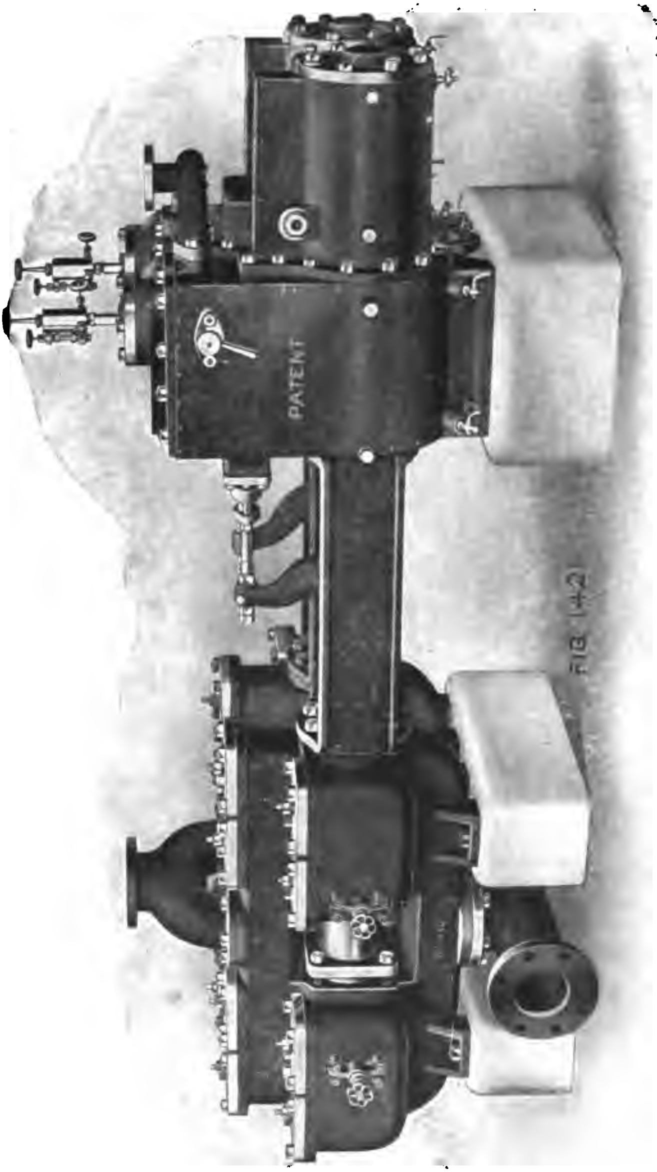


Fig. 68.—Odesse Compound Feed Pump.

The "Odesse" ram type compound pump (Fig. 68) is an example of the best class of horizontal duplex pumps. The valve gear is simple and has no external levers. The internal valves are arranged so as to have a perfect cushioning effect at the end of each stroke, and an ingenious arrangement in the form of a diaphragm plate, upon which the high-pressure steam operates, compensates for wear and keeps all parts tight. The lever seen on the outside of the steam chest is provided for adjusting the point of cut-off so as to obtain a "soft finish" to each stroke. This pump has many points to recommend it on the score of reliability and also economy in steam consumption.

TURBINE PUMPS

There cannot be much question that the turbine feed pump offers many advantages over every form of reciprocating pump.

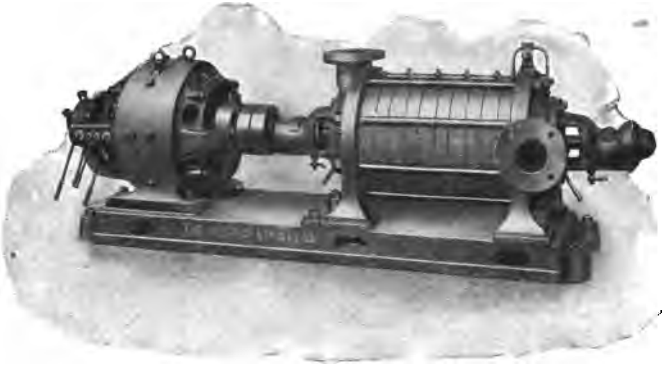


FIG. 69.—B.E.P. Turbine Feed Pump.

It can be designed for almost any head (pressure) and capacity, and requires the minimum of attention when running; in fact, less attention is required for the pump than for the electric motor driving it. The pressure of the water will only rise to a maximum of 20 % above the working pressure at full duty if the delivery valve is closed, and therefore an electrically-driven turbine pump only requires starting up and inspection of the bearings. In addition, the reduction of space required for installation, together with entire absence of steam and exhaust connections, render the turbine pump an ideal machine for boiler feed.

Turbine pumps consist of a number of centrifugal pumps or stages, enclosed, and held together by longitudinal bolts, the number of stages depending upon the head or working pressure. Intermediate pressures are obtained by design of the motor in regard to speed.

A typical motor-driven feed pump is the B.E.P. (The British Electric Plant Co.), as shown in Fig. 69.

Each stage consists of an impeller running concentrically with a diffusion plate, which distributes the water evenly to the parts around the outer portion of the chamber which forms one-half the casing, a closing plate serving to make the casing complete. The common shaft, on to which all the impellers are keyed, runs in two ring-oiled bearings, with a gland and stuffing box at each end of the shaft.

INJECTORS

On small plants, or with single portable or locomotive boilers, an injector is the usual method of feeding. Where no source of heat is available that otherwise would be wasted, an injector forms what amounts to a convenient combination of live-steam heater and pump.

The objection to injectors in connection with economisers has been dealt with in Chapter X, and as every stationary boiler installation should be equipped with economisers for maximum efficiency, the consideration of injectors in connection with such plants is scarcely compatible with the objects of this volume.

As a steam feed pump exhausting through a feed heater gives a very high efficiency indeed, this type of equipment is (apart from turbine pumps) the only one that should have consideration in connection with new plants or reconstruction of older batteries of boilers, and injectors should only be fitted as a reserve or stand-by.

AUTOMATIC BOILER-FEED REGULATORS

During recent years automatic feed devices to do away with hand regulation of the water supply to boilers have been gaining favour among engineers.

The greatest value of these feed regulators, in the author's opinion, is their effect in maintaining the efficiency of a plant where economisers are installed. In order to ease himself of some of the work during heavily-loaded periods the stoker is apt to allow his water level to fall, making this up again when the steam demand has diminished, such as during meal times, etc. The result is that when the gases are at their greatest volume, at periods of heavy work, the temperature in the economiser often exceeds that of the working steam-pressure, necessitating by-passing of a portion of the gases to counteract this effect.

On the other hand, water is pumped into the boilers when the temperature and volume of the flue gases are at their lowest, and therefore a very large portion of the feed water does not do its share in the heat recovery process.

By the use of an automatic regulator the water flows into the boilers at exactly the same rate as it is evaporated, and consequently the flow is strictly proportional to the heat available in the flues. As a consequence the economiser works at its maximum efficiency at all times.

In the boiler itself the advantages of regular feed which make for increased efficiency are, firstly, the avoidance of wet steam, which is often caused through high level of water and consequently restricted surface area. This reduction of area causes a more violent ebullition than the normal to take place, due to the steam having to be released from too small a surface. The result of this abnormal agitation is to project a large amount of

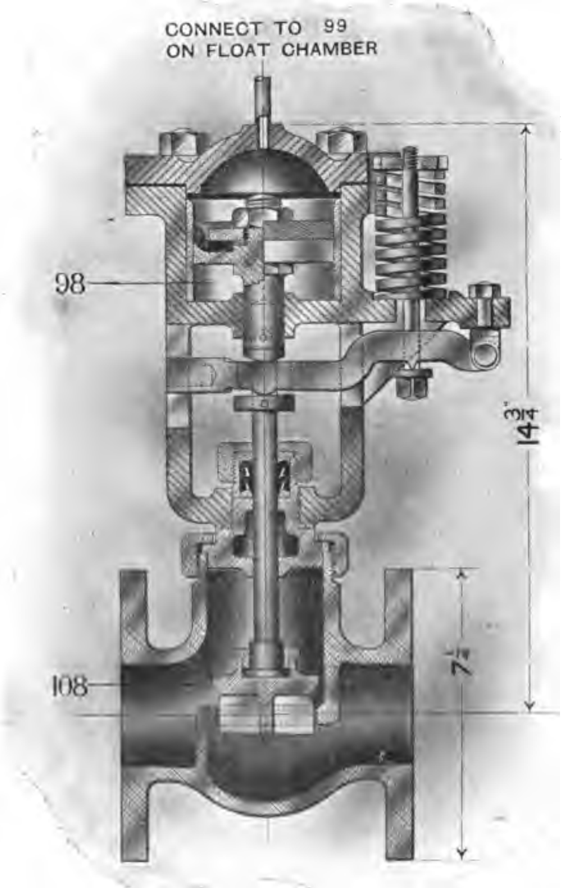


FIG. 70.—" Thermofeed " Valve.

spray into the steam space, this spray being carried away in the steam as unevaporated water or moisture, which, however, contains a large amount of heat which cannot be utilised.

Secondly, if the feed-water supply is at too low a rate, there is not sufficient volume of water in the boiler to absorb from the furnace the amount of heat for which the boiler has been designed, so the exit gases leave at an excessive temperature.

With too much water being supplied, besides the trouble of priming already mentioned, heavier firing is necessary to maintain the steam pressure, with the usual uneconomical results attaching to forcing. In this case, again, there is a large loss in the flue gases due to high temperatures.

There are three types of Automatic Feed Regulators generally in use, viz.—

1. The "Thermofeed" (Ronald Trist & Co., Ltd.);
2. The "Crosby" (Crosby Valve & Engineering Co.);
3. The "Anthony" (Robert Warner & Co.);

all of which differ in essential details.

1. The "Thermofeed Regulator" consists of two parts, one being a valve (Fig. 70) operated by steam on a spring-loaded piston which works in a cylinder situated above the valve itself. The valve is connected in the feed pipe at any convenient position.

The admission and exhaust of the steam operator piston is derived from a small pilot valve in the "Thermofeed" (Fig. 71). This small valve is worked from a ball float which is specially constructed to be balanced, and has the same pressure on its inner side as on the outside. This result is obtained by the ingenious device of sealing a certain quantity of water within it during manufacture.

This ball float is situated in a chamber beneath the pilot valve and operates the latter by means of an arrangement of levers as shown. The top of the float chamber is connected with the steam space of the boiler and the bottom with the water space by means of pipes. The position of the "Thermofeed" is so adjusted that at the correct working level steam is connected to the valve piston holding the water valve on its seat. When the water level falls, causing the float to descend in its chamber, the steam is released from the piston and the spring opens the valve, thus feeding the boiler.

To put the regulator out of action and feed by hand in the ordinary way, the small wheel valve on the connecting pipe (seen in Fig. 71) is closed down, thus shutting the steam supply off. This small valve is provided with an outlet from the upper side to atmosphere, which releases the steam from above the valve piston, thus permitting the spring to hold the feed valve open.

2. The "Crosby Regulator" (Fig. 72) works upon quite a different principle to the regulator described above. In the sectional diagram, Fig. 72, the feed valve, T, is of the balanced

type; its spindle, at the top extremity, is fixed to the diaphragm M, from which the opening effect is obtained. This diaphragm

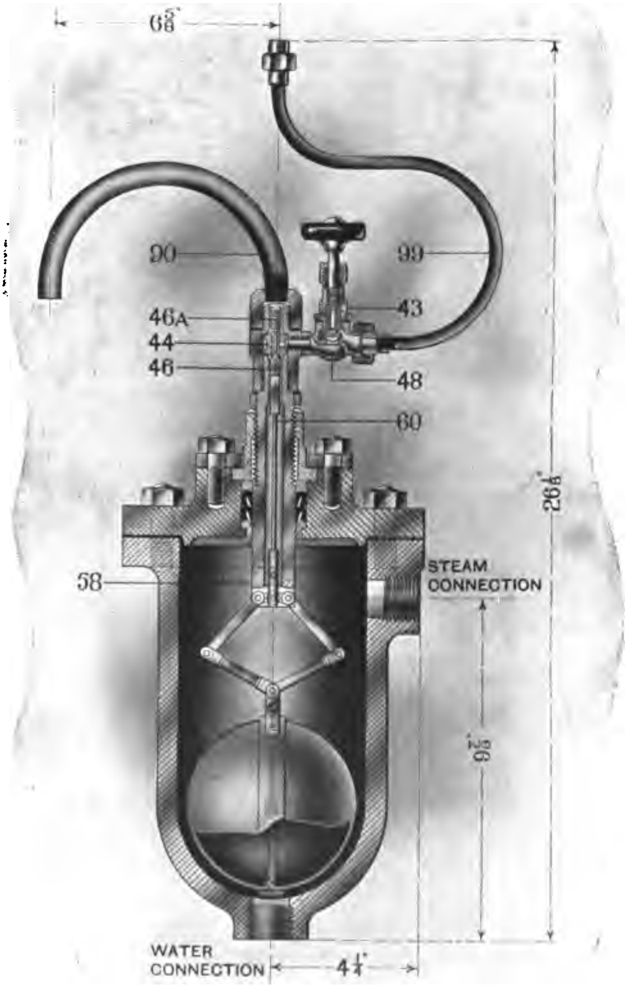


FIG. 71.—"Thermofeed" Regulator.

is subjected to a varying pressure of water derived from the hermetically sealed chamber D, which is evaporated, heated or condensed, according to the amount of steam or water beneath the partition G, which, as shown, has connections to the water and steam spaces of the boiler.

When water falls in the boiler, steam is admitted beneath the partition G, causing the water, D, to expand and evaporate and to exert pressure upon the upper side of the diaphragm M, thus opening the valve against the pressure of the spring P (which holds the valve T closed). As water rises in the boiler the steam leaves the underside of G, water replacing it, causing condensation in D, with resultant closing of valve T by the action of the spring P. The regulator is put out of action by pulling down and pinning the lever N.

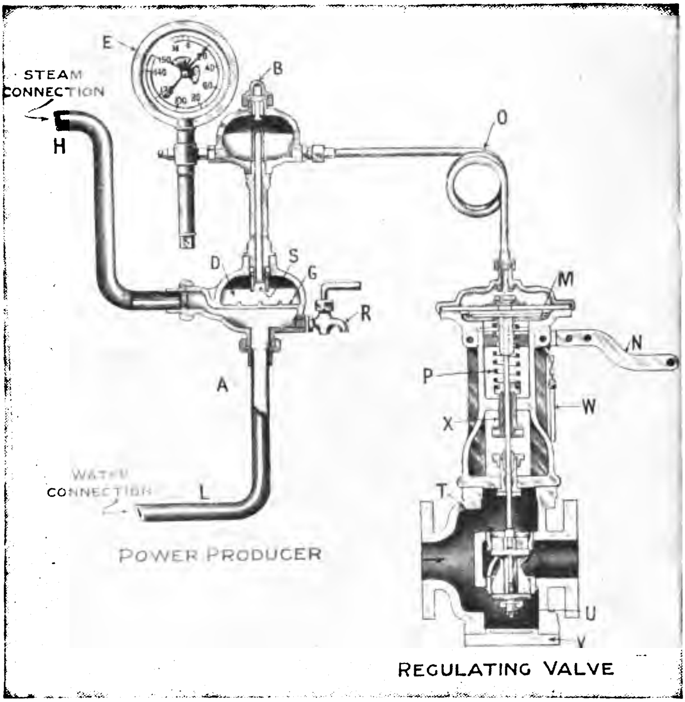


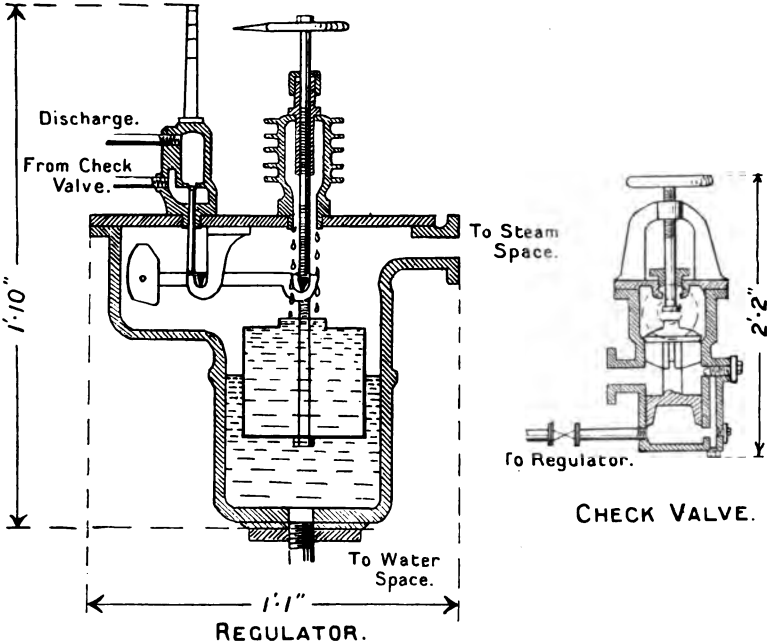
Fig. 72.—Crosby Feed Regulator.

In each of the feed regulators already described the ordinary feed check valve is retained on the boiler for hand regulation if required.

3. The "Anthony" Feed Regulator (Robert Warner & Co.) is quite a recent introduction and has three very distinctive features. The regulator valve, as seen diagrammatically in Fig. 73, displaces the usual feed-check valve, being in itself an

ordinary loose valve with hand-wheel spindle having an extension at the bottom. The casing of this extension forms a hydraulic cylinder in which works a piston attached to, and forming part of, the valve itself.

The float which controls the whole apparatus is of the open waterlogged type, kept full of water by a small air-cooled condenser above it which allows water to drip into the float. The position of the float can be adjusted on its spindle by an external hand-wheel to permit of changing the working level if desired. By altering the float on its rod, it changes the relative positions of float and the small operating valve by means of a counterweighted lever. At normal working level the feed valve is balanced by an equal pressure on each side of the piston, and the check valve works in the ordinary way. Balance is obtained by a plug in the side of the valve casing, specially constructed to allow leakage from the feed inlet to the underside of the piston. When the water rises in the boiler the float rises and gradually releases the water from beneath the piston, which thus holds the check value upon its seat.



REGULATOR.

CHECK VALVE.

FIG. 73.—Diagram of Anthony Feed Regulator.

By merely closing a cock in the pipe connection between the underside of the check valve piston and the operating valve the automatic control is cut out, leaving the check valve balanced and free to operate by hand.

The waterlogged float obviates the possibility of leakage in a hollow float, the working level may be varied, and by combining the automatic valve and feed-regulating valve in one, the necessity for a separate hand-operated valve is obviated.

FEED-WATER METERS

Unless a battery of boilers is provided with a suitable means ot measuring the amount of water evaporated per hour or per lb. of fuel, there is no method of definitely ascertaining the performance of the boilers and the return in steam for the amount of fuel burned.

It is quite useless to hope for any improvement in boiler efficiency if means are lacking for the purpose of finding out the existing state of affairs to begin with.

Using a water meter, we have a continuous record of the output of steam over any given period, by which the demand can be obtained together with the water evaporated per lb. of fuel burnt. With the addition of feed-water thermometers we can make a fairly close calculation of results in efficiency, and if the calorific value as well as the weight of coal is recorded the efficiency of the boilers may be ascertained very closely indeed (see Chapter XIII).

Perhaps the importance of feed-water measurement will be better appreciated by the parallel example of a business man buying raw material for some particular manufacture. If he is unable to check the raw material used against the quantity of finished articles produced one would be inclined to dispute his claim to the name of a " business man." This is exactly the position of the owner or engineer-in-charge of a boiler plant, the great majority of such being quite unprovided with any means of measuring the water supply, and thus being unable to check the output in heat in the steam against the coal used to produce it.

With a water meter installed in connection with a boiler plant one is provided with the first essential to observe the following points—

The quality of the coal used.
The amount of steam obtained per lb. of coal.
The normal demand for steam by engines and other plant and apparatus.
Any increase of demand as above which, without satisfactory explanation, requires special investigation.
The relative efficiency of the firemen.
The state of the boilers as regards cleanliness.

There are several types of reliable water meters, a selection of which will now be generally described. It should be mentioned that all boiler-feed meters should be suitable for use with hot water.

THE KENNEDY HOT-WATER METER

This meter is of what is termed the positive type, *i. e.* it measures every drop of water passed through it by the positive driving action of the water itself upon a reciprocating piston.

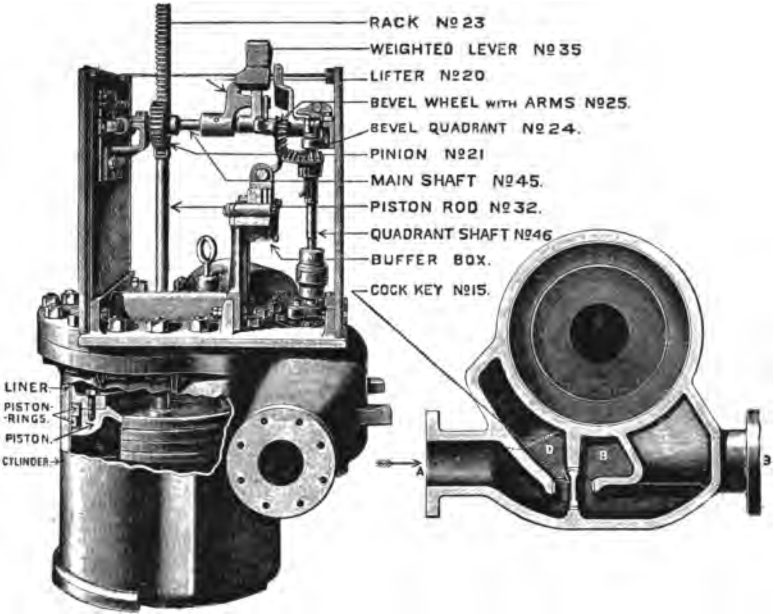


FIG. 74.—Kennedy Hot-water Meter.

It is shown in Fig. 74, and consists of a piston working in a cylinder which forms the pedestal or base of the meter. A piston rod projects through a stuffing box and gland vertically, the upper portion of the rod being a rack which communicates the reciprocating motion by means of a pinion to the counting gear. The counting gear is arranged to work in the same direction on either the upward or downward stroke of the piston and rod by means of a double ratchet and pawl wheel which forms part of the counting mechanism. A reversing cock operated by a vertical spindle which is moved through 90° at the end of each stroke by a throw-over gear with rubber buffers constitutes the valve motion.

Water leaking through the glands of this meter does not materially affect its accuracy, but leaky piston rings will interfere with correct registration, and these, therefore, should receive periodical examination.

As this meter registers the water by volume, in order to obtain the amount of water passed in lbs. a temperature correction is necessary (see Table in Appendix). Owing to its robust construction and absence of liability to getting out of order this meter has been adopted very widely for boiler-feed measurements.

THE LEEDS ROTARY WATER METER

The Leeds rotary meter as constructed for hot-boiler-feed purposes is shown in Fig. 75. In this meter the feed water in passing causes a set of vanes set upon a spindle to rotate, the speed being proportionate to the rate of flow. The spindle of the rotary vanes is geared to a clock train counter which records the number of gallons passed through. With reciprocating pump feed the addition of an ample air vessel is needed in order to somewhat equalise the flow by " rounding off the irregularities or ' kicks.' " If this precaution is not taken the meter will probably over-register. This meter also has to have a temperature correction applied.

THE LEA RECORDER

The "Lea Recorder" is a very accurate water meter for the measurement and integration of the flow of water through a **V**-shaped notch. The flow of water through a **V** notch of 90° is calculated as follows—

$$\text{Cubic feet per minute} = 0{\cdot}305\ h^2\sqrt{h}$$

where h is the height of water in the tank above the extreme point at the bottom of the notch in inches.

In the recorder under consideration the weir tank is connected by a pipe to another tank in which a float is situated, thus keeping the float unaffected by disturbance of the water surface in the weir tank. The second or float tank may thus be situated at any distance from the weir tank that may be convenient, the two tanks, of course, being on the same level with the junction pipe at the bottom. Again, the float tank may be placed either above or below the recorder directly so or with the float and recorder connected by a suitable arrangement of pulleys.

The recorder and integrator is shown in Fig. 76. The float rod at the left-hand side is connected to the float and is provided with a pointer working over a scale divided into inches. This pointer should stand at zero when the water surface in the weir tank corresponds exactly with the point of the **V** notch in the weir. The vertical motion of the float rod is conveyed by rack

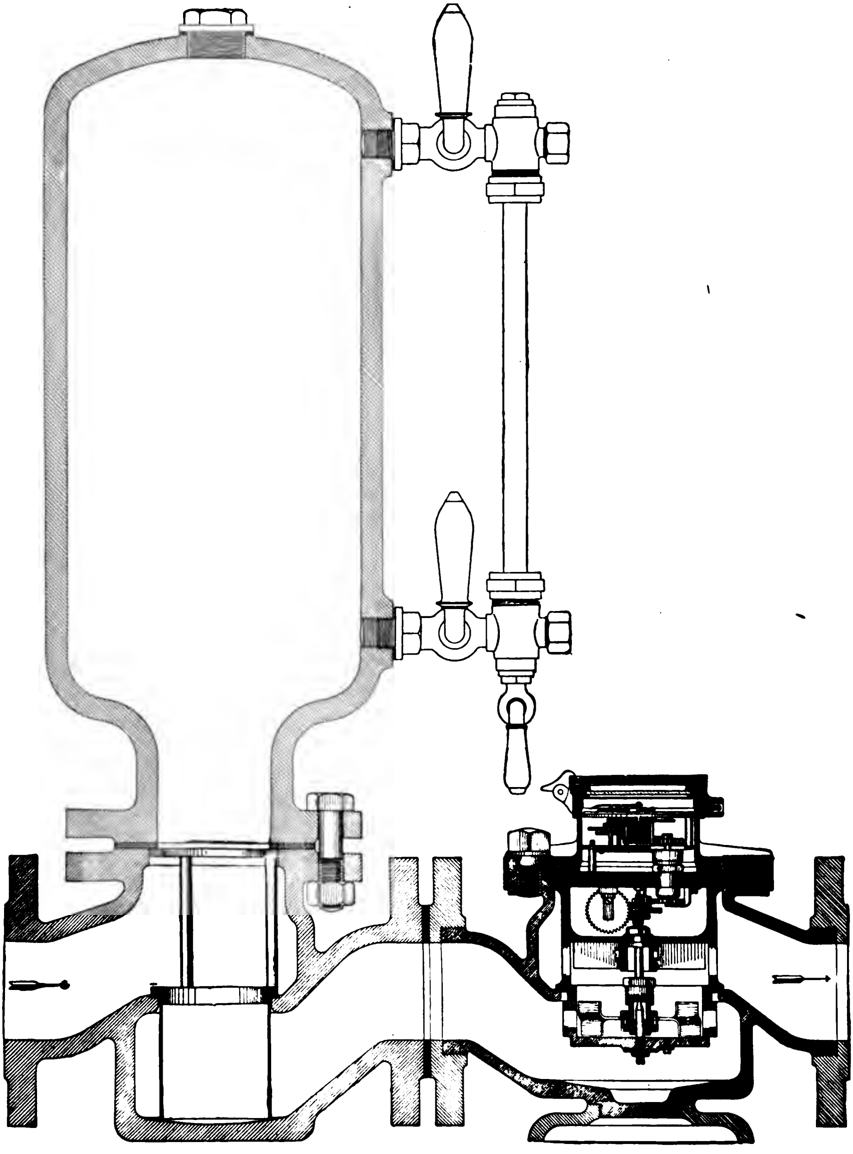


Fig. 75.—Leeds Rotary Boiler-feed Meter.

and pinion to the compensating drum, which has a groove or thread cut in it of increasing pitch calculated on the formula already stated. This groove gives a horizontal motion to the recorder pen and the counting dials directly proportional to the rate of flow represented by the height of the water in the notch, so that any equal area of the chart traced out by the pen indicates an equal volume of water passed. The quantity can therefore be accurately measured by means of a planimeter. The instrument shown in Fig. 76 includes an integrating gear with counting dials, the eight-day clock providing the driving mechanism for the necessary time factor for totalling the quantity passed.

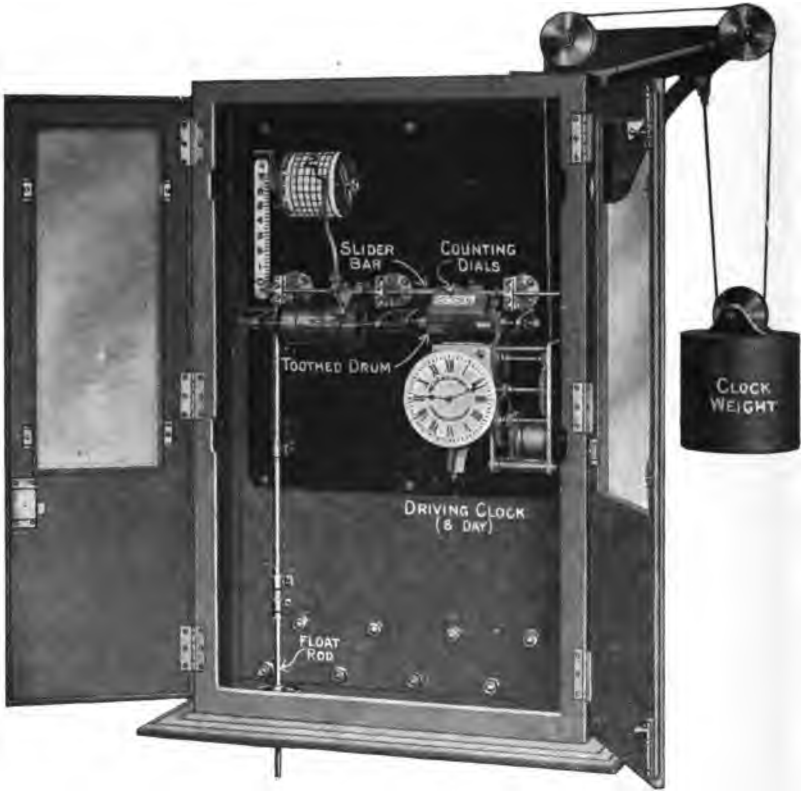


FIG. 76.—Lea Recorder.

The illustration shows a type of meter not now supplied unless specially ordered, a more compact form now being manufactured as the standard apparatus.

THE FLUXOGRAPH (Fig. 77)

This is another **V** notch recorder supplied by the Paterson Engineering Company, which differs from the " Lea Recorder " in the devices for correction and integrating. The grooved drum of the " Lea Recorder " is replaced by a plate with a curved edge which gives a horizontal motion to the rod carrying the recorder pen arm proportionate to the rate of flow. The horizontal bar is drawn back towards zero as the float falls by the weight of the counting gear. The bar also operates a pointer working over

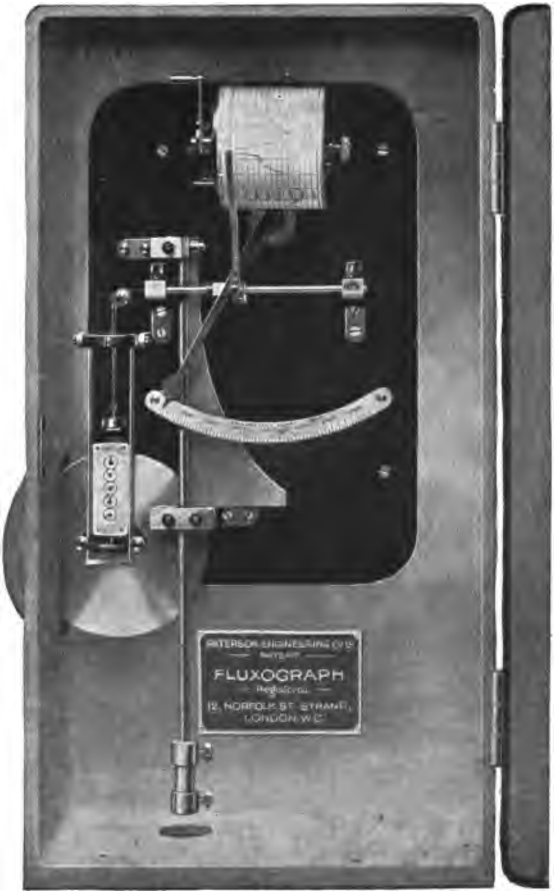


FIG. 77.—Fluxograph.

a dial graduated in gallons per hour, thus giving a direct reading of the flow at any moment.

The counting gear has a friction wheel at its lower end which, when the flow is at zero, makes contact with the clock-driven disc exactly on its centre point, so that although the disc revolves the friction wheel does not move. The float on rising also causes the counting gear to rise vertically towards the periphery of the clock disc, thus causing the friction wheel to revolve by the motion of the disc, the speed of revolution being proportionate to the distance of the friction wheel from the centre.

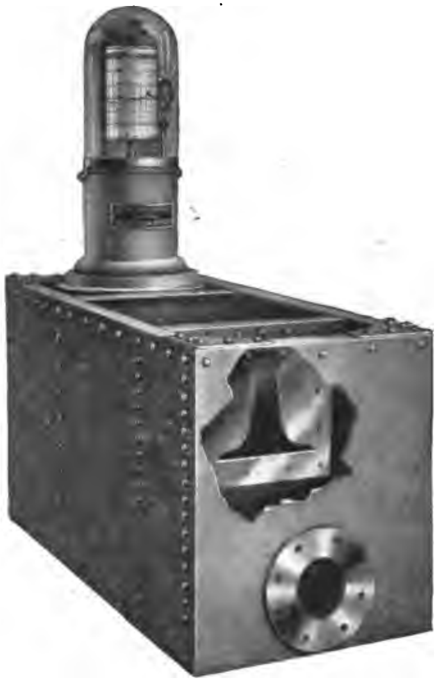


FIG. 78.—Precision Water Meter.

THE PRECISION WATER METER

This meter (Fig. 78), by making use of the " Yorke " weir, dispenses with all compensating devices in the recorder and meter. The weir notch, instead of being V-shaped, is cut in the shape shown, with the result that the height of the water in the float chamber is directly proportional to the rate of flow. The float rod is connected direct to the rod carrying the recording pen. The photo shows a self-contained recorder only, but when an integrating device is required a disc is fitted to the top of the recorder drum and revolves with it, a friction-driven counter travelling over it in a somewhat similar manner to the "Fluxagraph" integrator.

This meter is made by Messrs. Alexander Wright.

Flow meters of the three types described are, for all practical purposes, self-compensating in regard to temperature variations owing to the fact that although the water is of greater volume at higher temperatures the density is less, causing the float to be less buoyant in consequence.

THE VENTURI METER

When any fluid (in this case, water) is passed through a pipe of gradually diminished bore the velocity increases with a corresponding reduction of lateral pressure. If a U tube containing mercury has one of its legs connected to the larger bore of the pipe and the other leg to the small or throat portion of the pipe, the difference of pressure, as indicated by the difference of level of the mercury in the two legs of the U tube, will be a measure of the flow of water in the pipe.

The Venturi tube, as manufactured by Messrs. Geo. Kent, Ltd., is shown in section in Fig. 79. The water flows in the direction indicated by the arrow, entering the tube at the wide end or "upstream," passing through the throat and thence regaining the full bore pipe by the long taper portion of the tube. A pipe connection is taken from the "upstream" and "throat" to the recording and integrating apparatus (Fig. 80). The cast-iron mercury U tube is situated below the recorder, and one leg of this contains a float with a rack rod attached. This leg also serves as a support for the recorder. The recording pen rises and falls the full travel of the float, the integrator or counting dials being operated in a somewhat similar manner to that of the Lea Recorder; in this case one clock serves to drive both the recorder and integrating mechanism.

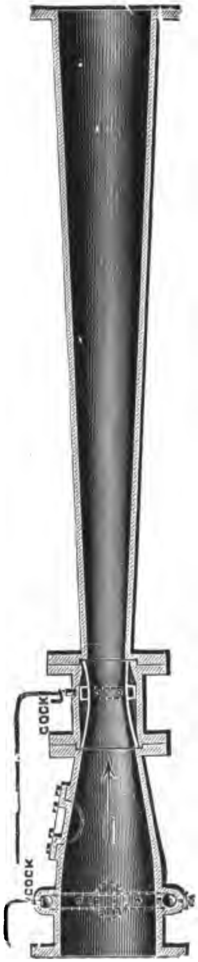


FIG. 79.—Venturi Tube.

To obtain accurate results in lbs. of water a temperature correction is required with the Venturi meter, as this registers gallons only. For ordinary working purposes, however, the meter is supplied calibrated for lbs. of water at the average temperature of the feed.

The Venturi meter has the great advantage that one recorder may be installed to register the flow through one of any number of meter tubes. As the recorder may be situated in any position up to 1000 ft. distant from the tube, it can be erected in the engine-room or any other suitable position.

The tube may be situated on the suction or the delivery side of the feed pump, and a very common arrangement is to have a tube in the feed pipe to each individual boiler, with a single recorder, which may be connected to record the evaporation of any one boiler that may be desired.

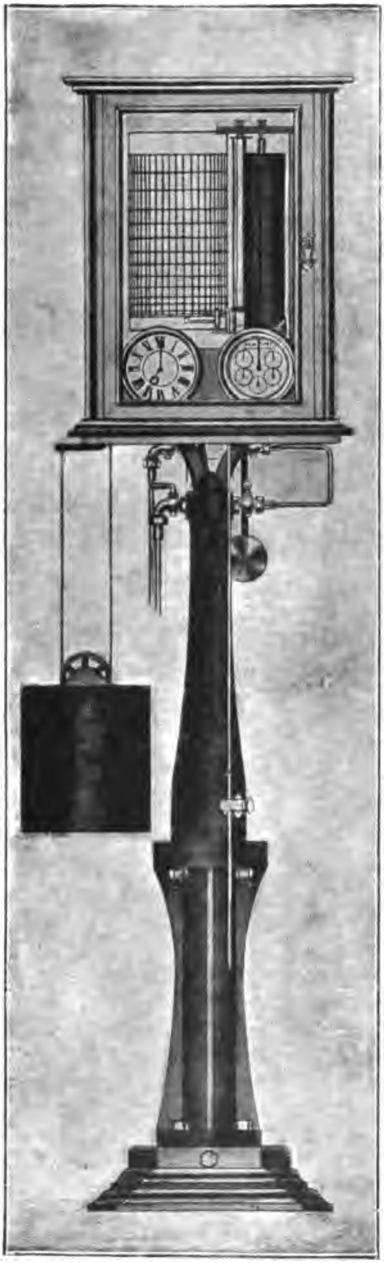


FIG. 80.—Venturi Water Meter.

SUGGESTED ARRANGEMENTS OF WATER METERS

For small boiler plants one meter of the Leeds Rotary or similar type connected in the common feed main is a very suitable arrangement. When injectors are used for boiler feed the meter must be installed on the suction side, or otherwise the steam condensed in the injector will be measured as feed water. The feed-water thermometer, of course, should be in a similar position.

For large batteries of boilers flow-meters of the Lea Recorder, etc., class are to be preferred, the pump suction being taken from the tank into which the weir tank discharges. The suction tank should have a float operating a valve which will control the supply of water above the weir. Where measurement on the suction is not possible or convenient the Venturi meter should be adopted, either with one recorder and tube for the whole supply or any subdivision that may be found desirable.

MEASURING WATER BY TANKS

A method used for the measurement of boiler feed when making evaporative tests is by means of a pair of tanks, one being filled to a predetermined amount while the other is emptying into a third tank to which the pump suction is connected. To obtain measurement of the water by weight direct, each tank is mounted on a separate weighbridge, the supply being changed alternately as the steelyard of the weighing machine indicates balance at the weight for which it is set.

For permanent measurement by weight in tanks, these are made of such a section that on reaching a certain level the water contained in the tank shifts the centre of gravity so as to cause the tank to tip over and empty itself into a suction tank. At the same time the water supply is automatically transferred to an identically shaped tank alongside which in its turn acts in the same manner, so that the two tanks alternately fill up and empty themselves. A counter gear is provided, from which the total water passed is calculated.

FEED PIPING

In such boiler plants where continuity of supply is of importance feed mains should be run in duplicate, one main connecting to the branches feeding one side of each of the boilers, and another to the other set of branches on the opposite side.

Not only because of the loss of efficiency, but also for reasons of safety, each main should be arranged to deliver through the economisers if required, where each boiler has a separate economiser.

By suddenly stopping the water supply through an economiser, especially on large boilers, the heat of the surrounding brickwork will cause the stationary water to boil, even if the gases are by-passed. It is for this reason that gases should be by-passed for some time before stopping the feed through an economiser, at any time it is intended to shut down.

In long feed mains expansion bends should be provided, and these must always lie in horizontal position, as an upright bend will probably create an air pocket, in a more or less short time, which cannot be released.

Where reciprocating pumps are installed, ample provision for minimising "hammer" should be made by means of air vessels situated near the pumps.

Cast iron is very satisfactory material for feed piping, even at high pressures, as it will resist corrosion much better than wrought iron or steel.

FEED TANKS

Feed-water tanks should have ample reserve capacity, and where used for hot water should be situated sufficiently high for the pressure due to the head to compensate for the reduction of pressure set up by the suction of the pump. If this is not attended to, it is possible that with the feed water at high temperature the pump will not deal with it, as the suction of the pump will reduce the pressure to that corresponding with the evaporation point of the water, with consequent formation of steam in the pipe.

The following Table gives the minimum height of feed-water tanks above the pump suction for various temperatures.

TABLE V

Temp. °F.	Minimum height of tank bottom.
up to 90°	level.
100°	3 ft.
110°	4 ,,
120°	5 ,,
130°	6 ,,
140°	7 ,,
150°	9½ ,,
160°	12 ,,
170°	14 ,,
180°	18 ,,
190°	22 ,,
200°	28 ,,

Feed tanks should be periodically cleaned and suitable covers provided to exclude dirt.

Suction connections must be made sufficiently high in the side of the tank to ensure that sediment does not find admittance.

By making the suction pipe extend into the tank with perforations below and closed at the top, risk of formation of vortices (" whirlpools ") and air admission are avoided. Aeration of water is a fruitful source of corrosion in pipes and boilers.

CHAPTER XI

STEAM.—Dry, wet and superheated steam—Total heat—Sensible heat—Latent heat—Specific heat—Conduction of heat—Steam pressure—Moisture test for steam—Steam pressure gauges, indicating and recording—Steam flow indicators and recorders.

STEAM may be defined as water containing sufficient heat to maintain it in the gaseous form.

Steam may also be accurately described as the vehicle by which the heat of the fuel is conveyed to the engine or turbine to be there transformed into mechanical energy, or for utilising direct in some manufacturing or other heating process.

Dry saturated steam is steam containing no moisture or suspended unevaporated water.

Wet steam is steam containing more or less unevaporated water in suspension which has been carried over from the boiler through foaming or priming. Although this water contains considerable heat it cannot be utilised for mechanical work, and is, in fact, a fruitful source of leaky pipe joints and water hammer, and therefore has to be drained from the pipes.

In speaking of "*saturated*" steam the term does not indicate a maximum quantity of moisture, but describes a state of complete saturation with *heat*, so that the steam consists of perfectly gaseous water.

Saturated steam has a definite temperature and quantity of heat per lb. for every pressure, and if more heat is added to the water in the boiler than is being utilised or taken away via the stop valve, the pressure will rise accordingly.

Dry saturated steam can be raised to almost any temperature, even to red heat, without increase of pressure by *superheating* or passing the dry steam through a series of tubes which are subjected to external heat either from an independent fire or in the flues of the boiler from which the steam is originally generated.

To obtain a clear understanding of the transformation of water to its gaseous state or steam we will consider what takes place when 1 lb. of water is heated at atmospheric pressure (0 lbs. gauge or 14·7 lbs. absolute pressure).

We have already seen in the earlier portion of this book that heat is measured by the rise of temperature in ° F. per lb. of water heated.

The rise of temperature from freezing to boiling point is 180° F., and the quantity of heat units (B.Th.U.) required to carry this out is about 180 B.Th.U. per lb. of water heated.

If we take 1 lb. of water at freezing point (32° F.) and steadily add heat until the total increase is 180 B.Th.U. the temperature of the water will be 212° F. In order to change the whole pound of water into steam or gas *at the same temperature* a further 970 B.Th.U. has to be added. This is called the *Latent Heat.*

If, instead of heating the water at atmospheric pressure, a closed vessel is used, then as the steam is generated and its pressure rises the heat required to evaporate a pound of water increases, but *the latent heat decreases.*

The explanation usually given for the phenomenon of latent heat is that it is the extra energy required to dissociate or break up the molecules of water from the liquid form into the gaseous state or to effect the physical change.

By reference to the Steam Tables in the Appendix it will be seen that the higher the pressure that is used the greater is the percentage of the heat in the steam available for useful mechanical work, therefore with two boilers working at an *equal efficiency,* one at 50 lbs. pressure and the other at 200 lbs. pressure, the latter will be considerably more economical in use of the heat of the fuel, thus—

1 lb. of steam at 50 lbs. pressure	sensible heat	267·5 B.Th.U.
	total heat	1178·5 „

Sensible or useful heat 23 % of total.

1 lb. of steam at 200 lbs. pressure	sensible heat	361·4 „
	total heat	1199·2 „

Sensible or useful heat 30 % of total, or 30 % better utilisation of the coal.

By adding further heat to the steam or superheating a still greater economy is effected, owing to the fact that the latent heat is unaltered, while the total heat is very considerably augmented.

To ascertain the heat added per lb. of steam per °F. the rise in temperature due to superheating has to be multiplied by a figure known as the *Specific Heat.*

Specific Heat is the amount by which the rise of temperature of any substance has to be multiplied in order to obtain the amount of heat added by such increase of temperature.

The specific heat of superheated steam varies with the temperature and pressure and may be obtained from the table in the Appendix.

Heat is transferred from the boiler furnace by radiation and convection to the plates of the boiler through which it passes, and is conducted through the plates to the water within, there transforming the water to the gaseous state as steam. This steam may pass from the stop valve in the dry saturated state or may carry with it a certain percentage of unevaporated moisture.

Moisture in Steam

By means of a water meter it may have been found that a certain quantity of water *appears* to have been evaporated by the boiler over a given period. With superheated steam this reading will be correct, but with saturated steam this may be far from the actual case. If through high-water level, forcing, excess softening reagents or sudden steam demands, priming is taking place to a more or less degree, so will the accuracy of the water meter as an indicator of evaporation be affected.

It is, therefore, of the greatest importance that the moisture in the steam should be determined so as to obtain reliable data in establishing the efficiency of the plant.

There are two methods of testing the percentage of moisture in steam, viz.—

1. The Condensation or Weighing Method.
2. The Wire-Drawing Method.

1. *The Condensation Method*

For this test a portable weighing machine is needed, also a barrel or other suitable vessel to hold about 20 gallons (200 lbs.) of water. This vessel must be very well lagged, preferably by means of an outer container as shown in Fig. 81, the space between the two receptacles being packed with slag wool.

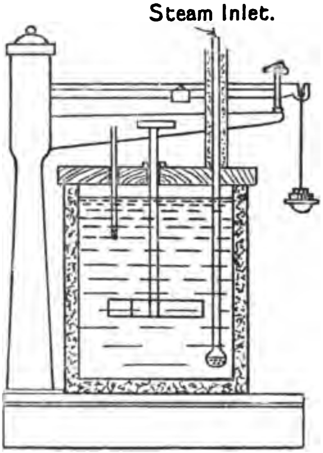


FIG. 81.—Condensing Calorimeter.

A tapping is taken out of the top of the steam main where the test is to be made, by means of a pipe, which must also be very well lagged with non-conducting covering. This pipe ends in a rose near the bottom of the water in the condensing tank. A valve is provided close to the steam main under test, and the whole apparatus should be placed as near to this as practicable so as to avoid, as far as possible, all losses by radiation.

A thermometer and stirring device is also required for use in the "calorimeter," as the apparatus is termed.

The vessel should be covered with a wooden lid with suitable openings just large enough to admit the steam pipe, thermometer and stirrer rod.

Place 100 lbs. of water into the calorimeter and allow to stand for at least one hour, so that the temperature may become steady. The water should be at the same temperature as regards the surrounding atmosphere as that given for the Thompson Calorimeter (Chapter II).

Taking as an example that the temperature of the water at the start is 60° F., steam pressure 100 lbs. per sq. inch., we have 100 lbs. of water in the calorimeter containing 28·12 B.Th.U. per lb., or a total of—

$$28\cdot12 \times 100 = 2812 \text{ B.Th.U.}$$

Steam is now passed into the water until an increase of 4 lbs. is registered, at which point the temperature is carefully noted. The water temperature has risen, say, to 100° F., and we now have 104 lbs. of water containing—

$$104 \times 68\cdot01 = 7073 \text{ B.Th.U.}$$

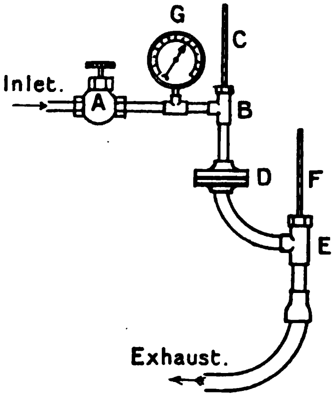


FIG. 82.—Barrus Wire-drawing Calorimeter.

The total heat in steam from 100° F. at 100 lbs. pressure is—

$$1188\cdot8 - 68\cdot01 = 1120\cdot79 \text{ B.Th.U. per lb.}$$

The dry steam condensed, therefore, is—

$$\frac{7073 - 2812}{1120\cdot79} \quad 3\cdot80 \text{ lbs.}$$

The percentage dry steam is therefore—

$$\frac{3\cdot8 \times 100}{4} = 95\ \%.$$

or 5 % of moisture.

Under the conditions given in the example a test of evaporation of a boiler would necessitate a reduction of 5 % from the apparent evaporation as shown by the water meter.

2. *The Wire-drawing Method*

The Barrus wire-drawing calorimeter is shown in Fig. 82 and is now very largely used for estimation of moisture in steam. As with the apparatus previously described the results are only approximate and no instrument has been devised, up to the present, to determine with scientific accuracy the amount of moisture present in steam.

The apparatus is very simple and consists of the following parts connected in series through which the steam is passed—

A is a screw-down valve connected through a short length of ½ in. pipe to the T-piece B, which is provided with a thermometer and cup C fitted as shown. D is a thin wrought-iron disc secured between two flanges, and having a hole ⅛ in. diameter drilled or punched through its centre. The outlet side of this wire-drawing disc is connected by a ¾ in. bore pipe to a second T-piece E and thermometer F to that at B and C. The exhaust is carried away through a sufficiently large pipe (say, 1¼ in. bore) to avoid any back pressure. The thermometer cups are filled with mercury in the usual way.

To use—

Open valve A wide and take frequent readings of the two thermometers and the pressure gauge G (which should be accurately calibrated).

The steam in passing through the disc D becomes superheated, the amount of superheat being dependent upon the difference in pressure before and after wire-drawing, and is reduced according to the amount of moisture present.

The formula for calculating the moisture is as follows—

$$M = \frac{H - 1150{\cdot}4 - {\cdot}48(t - 212)}{L} \times 100$$

where

M = Percentage moisture in steam.
H = Total heat in steam at boiler pressure, above 32° F.
$1150{\cdot}4$ = Total heat in steam at atmospheric pressure, above 32° F.
$\cdot 48$ = Specific heat of superheated steam at atmospheric pressure (14·7 lbs. per sq. in. absolute).
t = Temperature in °F. shown by thermometer F.
212 = Temperature in °F. of dry steam at atmospheric pressure.

The gauge G is provided as a check upon the thermometer C. The relation between the two should be that found by referring to the Steam Tables.

All the parts of this calorimeter must be carefully lagged.

STEAM PRESSURE

The importance of maintaining the steam at the highest working pressure and of utilising higher pressures in place of low ones is not always realised, especially in manufacturing plants.

The effect of latent heat has already been described earlier in this chapter, and its bearing upon economical working must be carefully borne in mind. Whenever machinery can be designed for working at higher pressures such as engines, turbines, steam hammers, etc., these should always be adopted. Although the first cost may be higher and lubricants more expensive, this will be rapidly wiped out by the reduction in coal consumption resulting from the alteration.

INDICATING AND RECORDING PRESSURE GAUGES

Following upon the foregoing remarks, the value of continuous records of steam pressure needs little additional emphasis; as such records may very often explain increases of coal consumption which are otherwise unaccountable.

The ordinary indicating steam pressure gauge is too familiar to all engineers to need any particular description, whether of the "Bourdon" or diaphragm type.

Recording gauges are of similar construction, with a pen and clock chart in place of the usual pointer and dial.

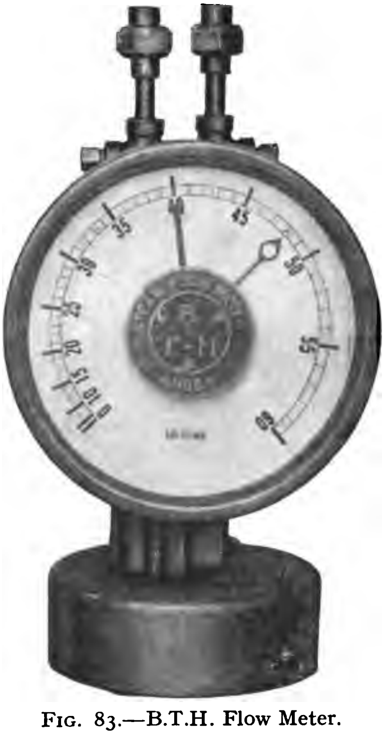


FIG. 83.—B.T.H. Flow Meter.

Pressure gauges, as a rule, tend to read too high with constant use, and should be carefully checked and adjusted from time to time by comparison with a standard gauge or else a dead-weight steam-gauge tester.

With saturated steam (not superheated) a *correct* pressure gauge will be sufficient for obtaining the temperature of the steam by reference to the Steam Tables.

For superheated steam a thermometer is required, preferably of the recording type, and may be either mercurial or electrical.

For pressure and temperature records the instruments should be mounted with the other apparatus in the "observation cabin."

Thermometers are introduced into the steam pipes by means of a malleable cast-iron screwed pocket, filled with mercury in the usual way.

STEAM-FLOW METERS

This class of apparatus has been coming into very considerable prominence of late years, and, in the author's opinion it is fully equal in importance to the steam-pressure gauge.

A steam-flow indicator installed on each boiler will provide for the fireman and engineer-in-charge an excellent guide as to the output that is being obtained and the effects that result with various methods of firing. It is thus possible to see at a glance which boilers are being forced and which are working correctly, or perhaps not doing their share of the work.

Steam-flow indicators work either on the Pitôt or Venturi tube principles.

The Pitôt tube principle is adopted in the B.T.H. Flow Meter, one type of which is shown in Fig. 83.

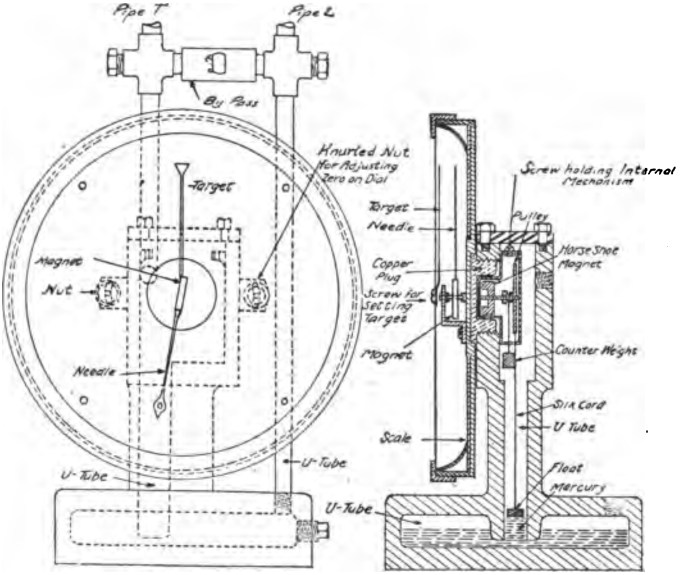


FIG. 84.—Diagram of British Thomson-Houston Steam-flow Meter.

A hollow plug is inserted into the steam main. This plug has a set of holes facing the flow of steam, and an internal tube is brought out to a hole at the opposite side of the plug, thus termed the "trailing" hole. The inner and outer portions of the plug tube are brought out through valves which are connected by a pair of small-bore iron or steel pipes to the indicator, which is usually mounted at the front of the boiler. This indicator practically consists of an enclosed mercury U tube, in one leg of which there is a float. The movement of the float within the casing is communicated to the needle on the dial by means of a horse-shoe magnet as seen in Fig. 84.

A difference of pressure is set up in the two pipes varying with the velocity of the steam in the pipe.

A similar indicator is used for the Venturi tube pattern, which is supplied for smaller pipes or for lower rates of flow.

The "*Sarco*" Steam-flow Recorder (Fig. 85) works on a similar principle and is provided with a temperature compensating device consisting of a fulcrum for the pen arm which varies its position according to the steam pressure.

The Pitôt tube arrangement is magnified in this instrument by making it in the form of a disc of slightly smaller bore than the pipe into which it is fitted. Connections are taken through diametrically opposite points in the thickness of the disc, each terminating in an opening in the face of the flange, one facing the steam flow and the other "trailing."

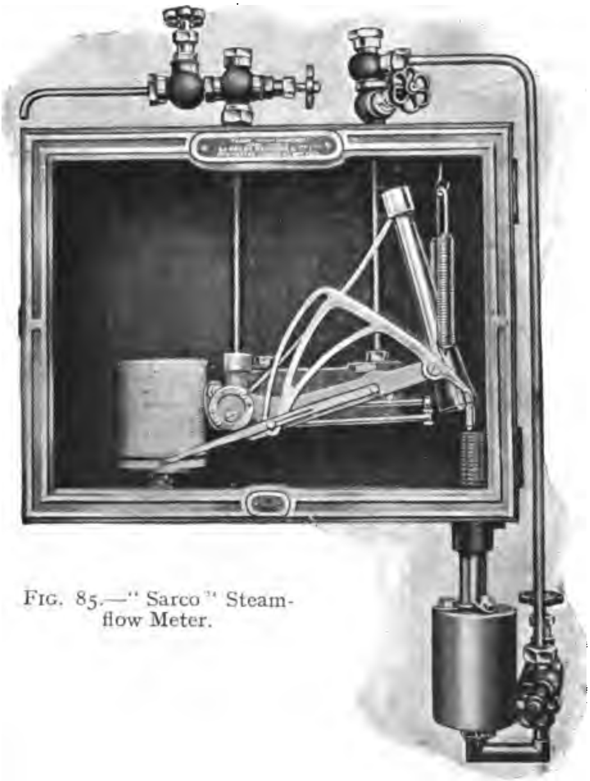


FIG. 85.—"Sarco" Steam-flow Meter.

The Bristol Differential pressure gauges and Flow Recorders are made for use with Venturi and Pitôt tubes, etc., and are of similar appearance and construction to their ordinary pressure and draught recorders, with the exception that an additional connection is made to a pressure-tight chamber surrounding the usual coil or diaphragm which is connected to the other tube.

CHAPTER XII

STEAM BOILERS.—Types: vertical cross-tube and multitubular; Cornish and Lancashire; Babcock; Stirling; Locomotive; Marine—Circulation of water—Heating surface and grate area—Combustion space—Superheaters.

STEAM BOILERS

IT is not proposed to enter into any details of construction of the various types of boilers described, but only the general arrangement and characteristics of each class will be dealt with.

VERTICAL BOILERS

The common small vertical cross-tube boiler is shown in Fig. 86. It may be constructed with one, two or three cross water tubes in the firebox, the heating surface being dependent upon the number of these cross tubes.

Apart from its portability, small space and low price it has little to recommend its use, being anything but economical.

As the ratio of heating surface to grate area in these boilers averages only 6 : 1, it is obvious that they are about the most wasteful form of boiler that it is possible to use.

The ordinary vertical tubular boiler differs from the above in that there are no cross tubes, but the furnace gases are taken up through the water space by a number of vertical smoke tubes, thus increasing the heating surface with an average ratio of heating surface to grate area of 15 : 1. But as the tubes are vertical and are not transverse to the current of water circulation the increase of efficiency is not so great compared with the cross-tube boiler as would at first appear.

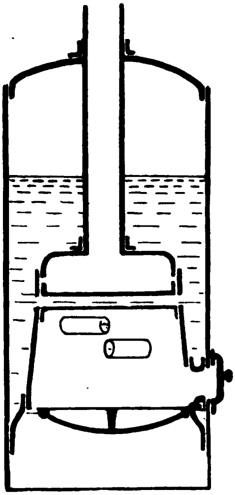


FIG. 86.—Vertical Cross-tube Boiler.

A better method of increasing the ratio is by making the firebox of rectangular shape and using the sides as tube plates into which are expanded a large number of water tubes slightly inclined. These water tubes should be in alternate rows at right angles to each other. This form of construction necessitates provision for dividing the outside boiler shell by a flange joint below the bottom row of water tubes, so as to make the tubes accessible for expanding, etc.

The Cochran boiler (Fig. 87) is a good example of a type of vertical multitubular boiler, which has very considerable advantages over the vertical boilers already described. These are built in a large range of sizes, the average ratio of heating surface to grate area being 18 : 1, or three times that of a vertical cross-tube boiler.

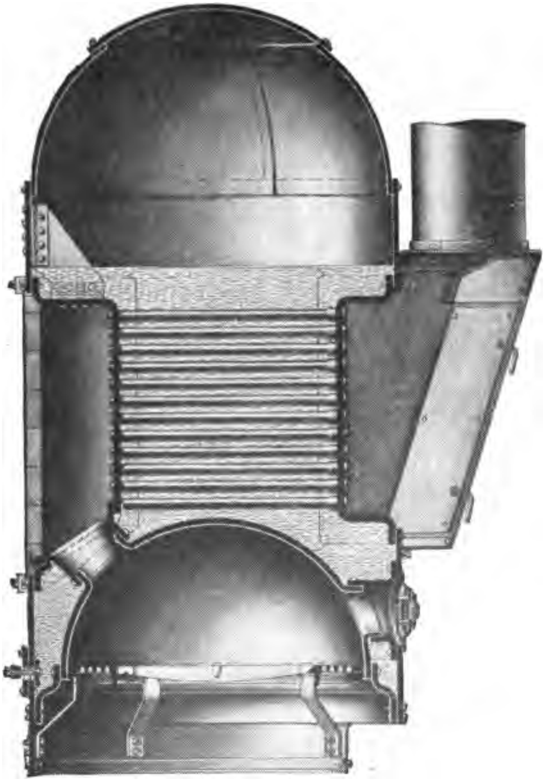


FIG. 87.—Cochran Multitubular Boiler.

The gases pass through a neck opening out of the hemispherical-crowned firebox into the combustion chamber, thence through the smoke tubes to the chimney. The smoke-box beneath the chimney is provided with a pair of doors, which furnish ready access to the tubes for cleaning.

It will be noticed that this boiler is somewhat similar in arrangement to a dry-back marine boiler, except that heat is applied right down to the lowest water space, with consequent accelerated circulation of the water.

As the passages of the principal heating surface (*i. e.* the tubes) are transverse to the circulation of the water, it is probable that this boiler represents the most efficient of the vertical class.

HORIZONTAL BOILERS

The Cornish boiler (Fig. 88) is a cylindrical boiler constructed with a single internal furnace and flue tube. In some cases this flue tube is on the vertical centre line of the boiler, and in others it is placed excentrically. The excentric construction gives more accessibility and better circulation.

This boiler, being only useful for small outputs, is scarcely to be recommended in preference to the Cochran type, and though the ratio of heating surface to grate area in both types is much the same for similar outputs, the Cornish boiler takes up much more ground space than the Cochran, and in addition requires a brickwork setting and flues.

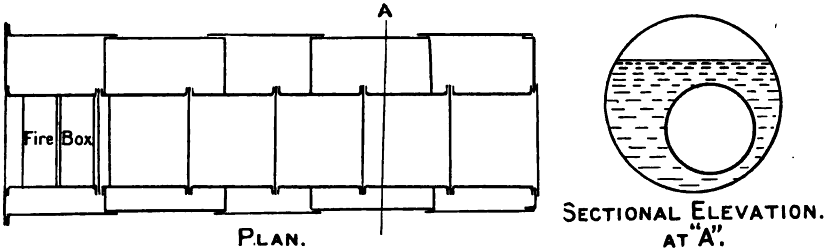


FIG. 88.—Cornish Boiler.

The Cornish boiler has this advantage, in common with the Lancashire and similar types of boiler, that, owing to the much greater volume of water as compared with tubular boilers, there is a greater reserve of heat to meet sudden demands for steam. On the other hand, the rate of steaming cannot be varied very rapidly, which may lead to considerable fuel loss through difficulty in preventing blowing-off at the safety valves when the demand for steam suddenly diminishes.

The Lancashire boiler (Fig. 89) is similar to the Cornish, and differs in having two internal flue tubes instead of one.

In all probability there are more Lancashire boilers at work in the United Kingdom than all other types combined (omitting vertical cross-tube boilers).

In this type of boiler there is an increase of heating surface compared with the grate area, the average being about 25 : 1, but even this cannot be considered as being sufficient for modern requirements. Therefore these shell-type boiler plants should never be installed without economisers and, wherever permissible, superheaters where efficiency is to be considered.

A Lancashire boiler plant, with careful operation and working with economisers and superheaters, will often show an efficiency of 80 %, which is comparable with the results obtained with the best modern water-tube boilers.

Galloway Tubes

These tubes provide an additional heating surface in Cornish and Lancashire boiler flues, but as they very seriously retard the draught, are productive of smoky and wasteful fires and consequent inefficient results.

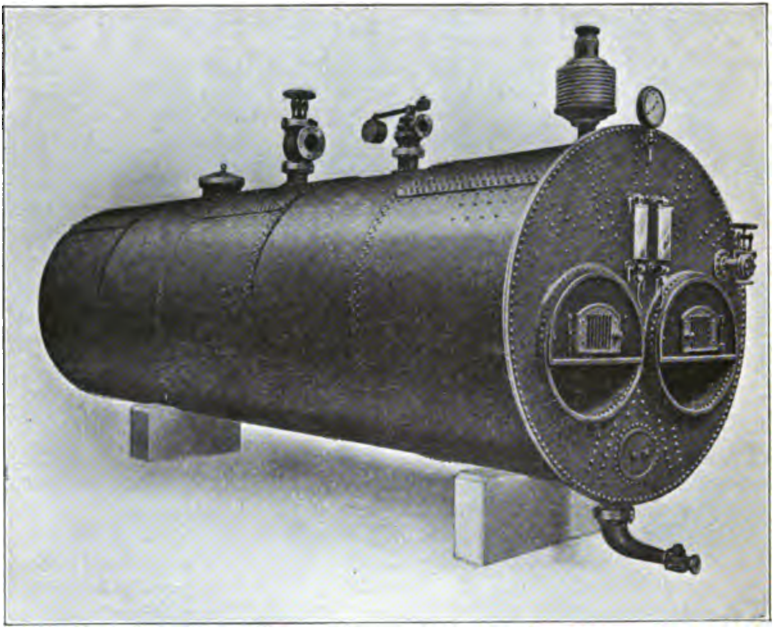


FIG. 89.—Lancashire Boiler by Messrs. Yates & Thom, Ltd.

They should never be specified for new boilers, and should be removed and the holes in the flue tubes blanked off wherever found in existing boilers.

Their value as circulators is of little or no importance.

By removal of these tubes it will be found that clearer and brighter fires are obtained, which more than compensates for the reduced heating surface by increased evaporation from the area that remains.

Lancashire and Cornish Boiler Flues

Even to this day there are boilers in which the gases from the flue tubes divide at the back and pass along the side flues, returning finally to the back of the boiler by the centre flue at the bottom, at the end of which the damper is fitted.

As it is of the greatest importance that as much heat as is practicable should be imparted to the water in the bottom of the boiler to ensure circulation, the gases should pass along the bottom of the boiler before finding their exit by way of the side flues.

Another arrangement of flues is by setting the boiler upon a mid feather wall longitudinally, this wall being provided with transverse piers or baffles at intervals alternately with similar piers projecting from the side walls. The gases enter a downtake at the back end, passing to the front of the boiler by a serpentine path along one side of the bottom of the shell, returning in a similar manner on the other side to a single damper.

This arrangement results in uneven heating and distortion of the boiler shell, poor draught caused by the tortuous path of the gases and rapid filling of the flues with flue dust, combined with maximum inconvenience in cleaning; the external heating surface of the boiler is also very greatly reduced by the large total area rendered ineffective by the brick piers or baffles.

It must be borne in mind that once combustion is complete the volume of the gases decrease with the fall in temperature, and as the efficiency is dependent upon the velocity (see Chapter XIII) the flues should generally tend to decrease in area towards the dampers.

Water-tube Boilers

For large plants water-tube boilers are now almost exclusively used, owing to their large steaming capacity compared with the space occupied. Their high efficiency even without economisers has brought them into universal use in such places as electric power stations, where the coal bill is the principal factor in determining a profit or a loss. As these undertakings are usually in keen competition with other forms of power and lighting, it can be well understood that they have always been foremost in obtaining the highest efficiency with steam-raising plants.

The Babcock Boiler

Probably the most widely used water-tube boiler in this country is the Babcock and Willcox, which is shown in Fig. 90 in its usual form, or " land type," fitted with superheater. The design of the boiler is so familiar to all engineers that it will not be described in detail.

Water is fed into the drum or drums at the top, the colder water passing down the cooler pipes at the back end of the boiler, and thence up the inclined water tubes, where it is largely evaporated, and is then discharged through the front headers into the front end of the drum. To prevent spraying and priming a baffle is arranged over the upper openings of these headers. Steam is taken from the back end of the drums for the same reason.

Where a superheater is fitted the steam passes from the anti-priming pipes down through the bottom of the drums into the bottom header box of the superheater, circulates through the steel hairpin-shaped tubes, where it is superheated, and finally leaves the boiler by way of the top header box and stop valve.

The hot gases from the furnace pass directly upwards through the water tubes, and after travelling through the superheater again traverse the water tubes in a downward direction to the middle or soot chamber, where most of the flue dust is deposited, owing to the locally reduced velocity. The gases again rise through the water tubes at the back end, and pass out between the downcomer tubes to the damper.

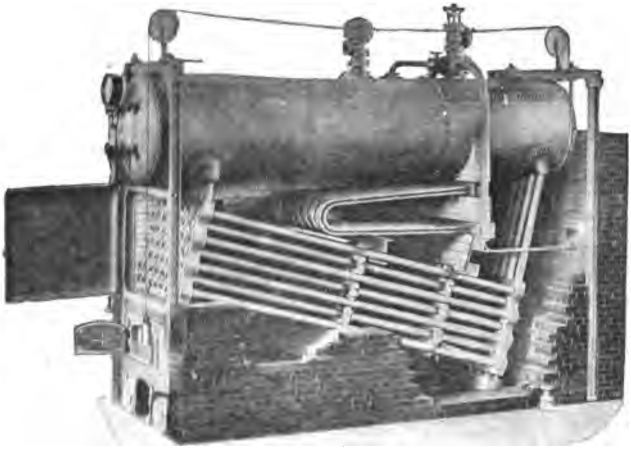


FIG. 90.—Babcock and Willcox Land-type Boiler.

It is very important that the headers and connecting nipples should be carefully protected against air leaking between them, as it is quite impossible to make the large front tube doors perfectly air-tight. The headers are tightly caulked with asbestos yarn for this purpose, and the spaces between the nipples fitted with bricks cut to fit.

The back headers should also be caulked with asbestos yarn, so that the last pass of the gases is not short-circuited to the dampers.

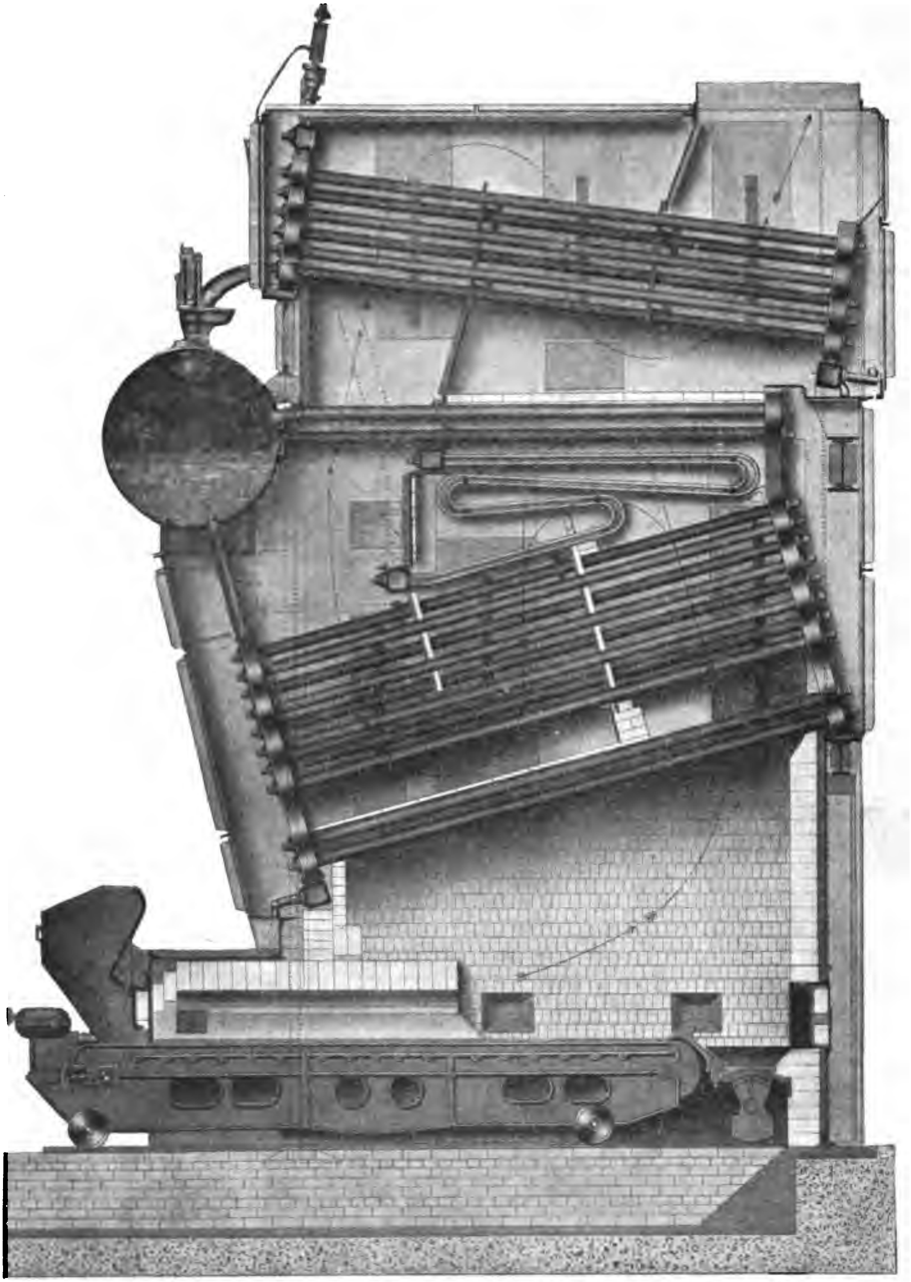


FIG. 91.—Babcock and Willcox C.T.M. Boiler with Superposed Economiser.

Another type of Babcock boiler, known as the C.T.M. (Cross Type Marine), was primarily designed for marine work, but has been largely adopted for land use, owing to its compact construction. In Fig. 91 a side elevation of one of these boilers fitted with chain-grate stoker, superheater and superposed economiser is shown, an arrangement now being adopted in some of the new power houses.

The very large combustion space necessary for the long grate will be noted, the path of the gases being distinctly indicated by the arrows.

The space between the second and third rows of tubes above the fire forms the soot chamber.

The superheater has a very large heating surface, due to the sinuous form adopted for the tubes, which utilises the available space to the best advantage.

Access to the tubes in all Babcock boilers is obtained by hand holes at each end in the headers. The hand-hole covers only need cleaning by means of a sheet of emery cloth laid face upwards upon a flat metal plate. A touch of boiled oil around the cap face and seating is sufficient to make a tight joint.

The Stirling Boiler

The standard Stirling boiler consists of five drums arranged as shown in Fig. 92 and connected together with almost vertical water tubes.

The tube ends are expanded into holes in the drums, from which they project radially for a few inches, and then are bent to a radius of 2 ft. 6 in. to a varying degree as required.

Water-balancing tubes connect the two lower or mud drums.

Both steam- and water-balancing tubes are provided between the top front and centre drums, and steam tubes only between the top back and centre drums.

Water is fed into the top back drum, passes to the back mud drum, up the tubes to the centre top drum, down again to the front mud drum, and is finally evaporated in the front bank of tubes. The steam collects in the front and centre drums at the top, and the stop-valve is fitted in the centre drum, so as to avoid priming, as the water is lower in this than the front drum and higher than in the back drum.

When a superheater is fitted, this is placed in the space between the upper ends of the front and second banks of tubes, and is either U shape or, where greater superheat is required, like an elongated letter S on its side.

The gases from the furnace enter the combustion space in front of the first bank of tubes, pass up the first bank, down the second bank, up the third bank, and then pass down through the last bank of tubes to the damper.

Where the water is not of a sedimentary nature the Stirling boiler is very satisfactory and has a very high steaming capacity, but with scale-forming salts in the water it is very apt to develop leakages and bursts in the bent portions facing the fire, owing to the great difficulty in thoroughly cleaning scale from these bends.

Straight tube boilers are to be preferred where the feed water forms heavy scale.

As all water should be filtered and treated before use in any boiler, so that deposit will not form, the objection to curved tubes should not be existent. Both the types of water-tube boilers described are only supported at the upper drums, the pendant form of the remaining portion allowing freedom of contraction and expansion.

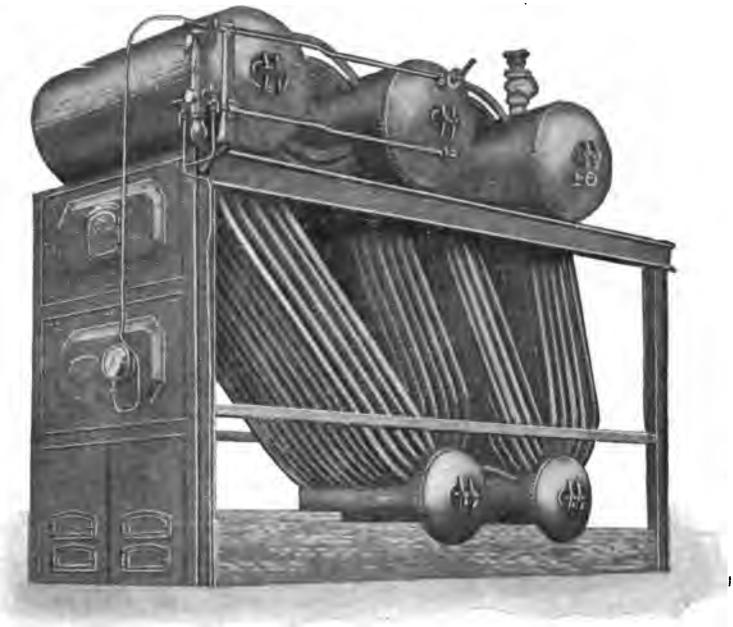


FIG. 92.—Standard Stirling 5-Drum Boiler.

The ratio of heating surface to grate area of water-tube boilers may range from 30 : 1 in the smallest sizes to 52 : 1 in the largest sizes, with grate area in the latter case of 204 sq. ft.

The Locomotive Boiler (Fig. 93)

Owing to its large heating surface, together with quick steaming power and portability, the locomotive boiler has many uses for which other types are unsuitable. The ratio of heating surface to grate area averages 35 : 1.

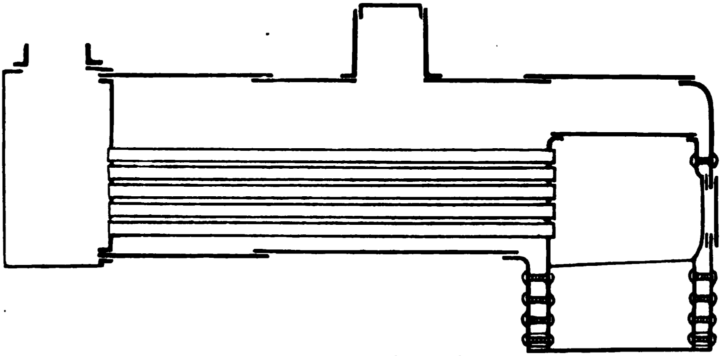


FIG. 93.—Locomotive Boiler.

The Marine Boiler (Fig. 94)

This boiler is still in use in some of the older plants, but is practically never installed nowadays for land practice.

It has small reserve steam space, thus being unable to deal satisfactorily with sudden and variable demands for steam.

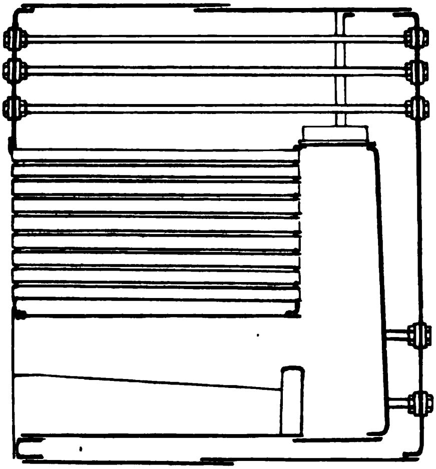


FIG. 94.—Marine Boiler.

The circulation is very poor, and without additional contrivances for promoting circulation is apt to develop leakages and fine fractures, owing to the great difference in temperature in different portions.

The dry-back boiler, or "Economic" type, is shown in Fig. 95. In this case the furnace flues pass right through the boiler, and the gases enter the smoke tubes from the outside at the back. After travelling forward through the smoke tubes the gases pass away to the main flue outside the boiler shell.

The "Economic" boiler is still very widely used for electric power plants, but has the disadvantages of the ordinary Scotch marine type in shortage of steam space.

Circulation of Water

Water, when heated, by reason of expansion loses density. thus reducing its weight per unit volume. The circulation of water in a vessel, therefore, depends upon the amount of temperature difference in various portions of the water. The hot water rises and the cooler masses of water gravitate to the bottom to replace it.

Water being a very poor conductor of heat, a very slow absorption of heat takes place when the circulation of water is not sufficiently rapid to bring every particle into contact with the hot plates.

With water flowing through an externally heated tube at a slow rate the water in contact with the walls of the tube is practically stationary, the velocity of flow increasing towards the centre. As the velocity of the water flow is increased the stagnant layer of water in contact with the heated tube becomes thinner, thus allowing the heat to be more generally distributed throughout the water.

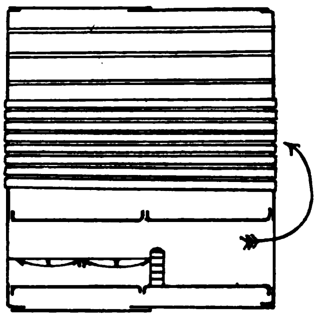


FIG. 95.—Dry-back Boiler.

The Babcock type of boiler may be compared with a U tube with its two upper extremities connected together. Heat is applied to one leg first and then passes to the further leg, but at lower temperature. The water in the leg subjected to the greater heat decreases in density and rises, being replaced by the cooler water in the second leg. It will be seen that a continuous circulation is set up.

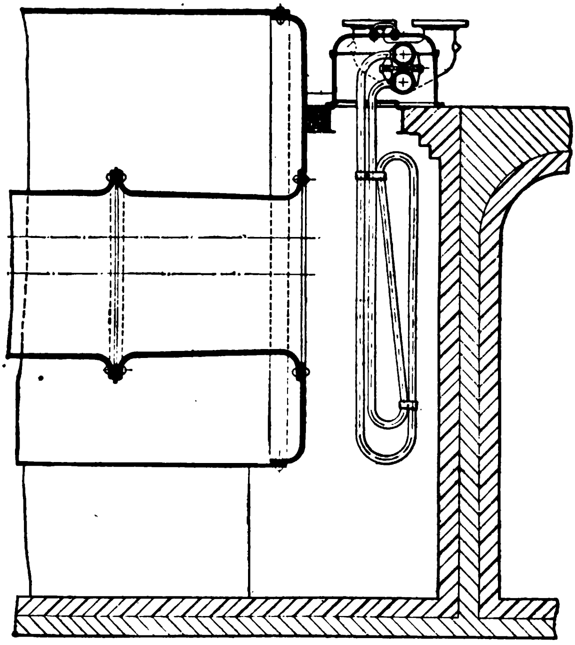
The Stirling boiler is also an extension of the same principle.

It may be taken as an accepted fact that the most efficient boilers are those having the most rapid circulation and in which the path of the gases is arranged to assist this movement most directly.

Water-tube boilers as a class fulfil these requirements to the greatest degree, although this is not invariably so, as in certain well-known makes of water-tube boilers the circulatory system is far from satisfactory, leading to leaky and bursting tubes.

On examining the construction of Lancashire and Cornish boilers it will be noted that the provision for down-flow of water is almost non-existent. This also applies to cylindrical marine type boilers.

The most satisfactory apparatus for improving the circulation in the boilers last named is the Hotchkiss circulator, already described in Chapter VIII in connection with its function as a remover of scum and deposit. By the provision of some effective device of this kind the efficiency and steaming capacity of cylindrical boilers will be much increased.



SIDE ELEVATION

FIG. 96.—Superheater for Lancashire Boiler (Yates and Thom).

Boilers of the locomotive type and multitubular boilers generally, although having a fairly large ratio of heating surface to grate area, are also defective in circulation, but are the best compromise where steaming capacity in small space is a consideration.

In forming an idea as to the probable efficiency of a boiler, attention should be paid to the amount of space provided over or beyond the fire for complete combustion. Theoretically, combustion should be complete, and the gases therefore at their maximum temperature, before any contact takes place with the relatively cool surface of the plates or tubes. If this is not properly provided for combustion is retarded, and possibly prevented from becoming complete. The gases being at maximum volume when at their highest temperature, the importance of this combustion space is apparent.

We may summarise the requirements for best efficiency in a boiler as follows—

1. Ample provision of combustion space over the fire.
2. High ratio of heating surface to grate area.
3. Free and natural flow of water within the boiler, accelerated by the relative positions of feed-water inlet and furnace.
4. Increase of velocity of gases through the boiler as they lose their luminosity.

Superheaters

The importance of superheat as a means of adding more heat to steam without increasing the latent heat, thus giving it a greater capacity for mechanical work, cannot be over-estimated. Another advantage is that if only sufficient superheat is added to maintain the steam in a dry state up to the engine, a great deal of loss of steam from leaking pipe joints will result, as this is caused in the majority of cases by water in the steam.

Superheaters in conjunction with water-tube boilers have already been mentioned, and a superheater for use with a Lancashire boiler is shown in Fig. 96. This particular form of superheater is supplied by Messrs. Yates & Thom, and is fitted in the downtake flue of a Lancashire boiler as shown. The number of these tubes used will vary with the diameter of the boiler and the degree of superheat permissible. For lower superheats plain hairpin-shaped tubes are used.

Where space is available or for other special purposes it is sometimes the practice to instal separately fired superheaters, the design of which is somewhat similar to the superheaters installed on individual boilers.

These independently fired superheaters are used where only a portion of the steam from a battery of boilers is required to be superheated.

CHAPTER XIII

PERFORMANCE OF BOILERS.—Transference of heat—Boiler efficiency—Steam boiler trials—Tabulation of results.

IN purchasing a boiler, some definite evaporation per hour in lbs. of water, also the efficiency, is specified for a certain grade and calorific value of fuel.

It is usual for a boiler to pass through the trials necessary to see that it complies with the guarantees given in the maker's specification, with an ample margin to spare. After a short space of time the purchaser finds that he is not getting the output or efficiency from the boiler that was obtained during the official trials. Very often the maker is suspected of some sharp practice or manipulation of figures, using incorrect instruments, etc., during the test.

Now it must be remembered that the maker's specification as to test guarantees is for a boiler exactly as he supplies it—plates clean, brickwork air-tight, fires and dampers correctly operated, etc., etc.—which is quite fair to all parties. Under these conditions it is almost invariably the case that the boiler does not only fulfil but exceeds the maker's guarantee.

Now for some reason, after a variable length of time, according to conditions of working, it is found to be apparently impossible for the boiler to repeat its performance as was shown under test.

On examination of the portions of the specification relating to the evaporation of the boiler the whole thing is summarised into an undertaking to supply a boiler that will effect a certain percentage transference of heat from the furnace to the steam.

The percentage of heat delivered from the boiler stop valve of that generated by the heat of combustion of the fuel is termed the *Thermal Efficiency.*

The points which assist or retard the transference of heat, and thus affect the thermal efficiency of the boiler, will now be considered before passing to the factors from which this is obtained.

Heat may be passed from one body or substance either by conduction or radiation.

When a hot body comes into contact with another body of lower temperature, heat is transferred with more or less rapidity from the hotter to the cooler body by the process of conduction.

Where the hot body is a solid and the cooler one a gas, currents of the gas are set up. As the temperature of the gas rises the density decreases and the hotter portions of the gas rise, being replaced by colder gas, which on becoming heated rises, thus forming a continuous circulation.

This process of heating a gas is adopted in the so-called steam radiators for warming buildings, etc., these being formed of a number of pipes charged with steam, and offering a large surface to the air. Currents of air thus set up are called *convection currents*, and the air-heaters should be properly called *convectors*.

When a body is heated, but not to luminosity, the air is heated entirely by convection, radiation in its correct sense playing no part in the operation.

Radiation of heat from a luminous body does not heat the gases through which it will freely pass, but is absorbed by and raises the temperature of any solid or opaque body upon which it may fall. This solid body in its turn will warm the surrounding atmosphere by convection.

Applying the above principles to the boiler furnace and heating surfaces, the transference of heat by radiation is of the greatest importance while the gases are still fairly luminous, gradually being displaced by conduction as the gases become non-luminous due to abstraction of heat.

The principles applying to the flow of fluids (liquids and gases) through a pipe or other channel are that the portions nearest to and in contact with the walls of the pipe are almost stationary, the velocity increasing towards a maximum at the centre.

The film of inert gas in contact with the boiler plates is of comparatively small importance while the gases are still luminous, as the transference of heat is carried out by radiation, to which the transparent film offers no obstacle.

Now the amount of heat transferred by conduction depends upon the difference of temperature and specific heat of the hot and cold bodies, and therefore in order to effect the greatest exchange it is necessary to keep the hottest part of the gases in intimate contact with the plates of the boiler. In straight-flued or multitubular boilers the film of inert gas next to the heating surface depends for its thickness upon the velocity of the gases; the greater the velocity the thinner the film will be. Even then it will be seen that without some deflecting or "mixing" device the centre portion of the gas current will have little chance of coming into contact with the plates of Lancashire or Cornish boilers, and after radiation ceases will lose very little more of the heat. In multitubular boilers deflectors or twisted strips of flat metal are sometimes inserted into the tubes for the purpose of bringing all parts of the gases into contact with the heating surface.

Special cones of refractory material, with the apex of each facing the flow of the gases, have also been used in Lancashire and Cornish boilers for the same purpose.

The objection to these devices is that in most cases they interfere seriously with the draught, causing incomplete combustion, and in multitubular boilers using bituminous coal the smoke tubes are rapidly sooted and blocked up from the same causes. Soot and external deposits are also very poor heat conductors.

In water-tube boilers, owing to the involved passages of the gases between the tubes, the mixture of the hotter and cooler portions is very efficiently carried out, with a consequently low final temperature and good transference of heat or thermal efficiency.

However good a conductor of heat a boiler-plate may be, it offers some small resistance or opposition to the passage of heat. As the thickness of a boiler-plate or tube is determined by its suitability to withstand the pressure of steam required, with a satisfactory margin of safety, discussion of this factor is of little or no importance.

The resistance of scale on the water-side of the boiler-plates or tubes to the passage of heat has been very fully discussed.

The action of the water is very similar to that of the hot gases. Water being a very poor conductor of heat, a more or less thin layer in contact with the plate offers considerable opposition to the flow of heat, this obstacle being reduced as the rapidity of circulation increases.

Applying the foregoing considerations to the subject of reduced output and thermal efficiency in boilers when compared with the test results, it will be realised that there are a number of factors which, perhaps individually small, may, in the aggregate, be the cause of very considerable loss of efficiency and consequent waste of fuel.

As to the actual operation of the fires, the representative of the boiler-maker will see that this is carefully carried out, working with the assistance of CO_2 testing apparatus, pyrometers and draught gauges to attain this end. The water in the boiler will also be carefully maintained at a constant level in the most efficient position.

It is unfortunate that many engineers are apt to dismiss " test conditions " as an artificial state of affairs that cannot be maintained in actual practice. Admitting that to a certain extent there is a degree of truth in this assumption, yet it is too frequently adopted as an excuse for inefficient conditions that should not exist. There are numbers of power-station boiler-plants working daily under such " test-conditions " with results that repay many times over the outlay of money and time involved.

The efficiency of a boiler can only be determined by a carefully conducted trial or test. To be of any value at all nothing in the nature of an estimate or assumption is permissible as a factor in obtaining the final results.

In carrying out a boiler trial the readings taken should be sufficiently complete to determine not only the efficiency of the boiler but also to ascertain with the highest possible degree of accuracy the different causes of loss. That is to say, the engineer must obtain sufficient data to be able to construct a "heat balance" sheet accounting for the whole 100 per cent. of the heat value of the fuel used during the test.

The data required from the readings obtained during the test are as follows—

1. The total heat content of the fuel fired.
2. ,, ,, content of the steam delivered at the stop valve.
3. ,, ,, of the feed water entering the economiser.
4. ,, ,, of the feed water leaving the economiser.
5. ,, ,, transferred in the boiler.
6. ,, ,, transferred in the superheater.
7. ,, ,, transferred in the economiser.
8. The heat lost in the flue gases.
9. ,, ,, by "radiation."
10. ,, ,, in the ashes.
11. ,, ,, by moisture in the steam.
12. Overall efficiency of complete unit in per cent.
13. Percentage of heat transferred in the boiler alone.
14. ,, ,, ,, ,, economiser alone.
15. ,, ,, ,, ,, superheater alone.

The testing apparatus required will be as follows, the accuracy of which must be of the closest, viz.—

Water meter or measuring tanks.
Thermometer for water temperature entering economiser.
,, ,, ,, leaving economiser.
Steam pressure gauge.
Superheated steam thermometer (reading to 800° F.).
Pyrometers for gases leaving boiler.
,, ,, ,, economiser.
Draught gauge over fires.
,, ,, at downtake or middle chamber.
,, ,, at dampers.
Orsat gas-testing apparatus.
Coal scales.

Other data required will be grate area, thickness of fires, stoker speed, current or steam consumption of fan, stoker, pump and economiser drive, weight of ashes removed, price of coal, description and class of coal used.

The first factor in a boiler trial requiring attention is the coal used.

At regular intervals, say of a quarter of an hour throughout the test, samples of coal must be taken with a small hand-shovel and placed aside on a clean space on the stokehold floor. At the completion of the trial this aggregate sample is cracked up, well mixed and quartered down to a conveniently sized final sample as described in Chapter II. About 2 lbs. should be placed in an air-tight tin and labelled for future reference, and a sufficient quantity sent to the laboratory for a test of calorific value and evaporative power, together with a proximate analysis.

Careful weighing of the coal used in the fires must also be carried out, several methods of doing this being adopted to suit varying conditions.

The ashes removed must also be carefully weighed and a fair sample of these taken in a similar way to the coal. The ashes must be tested for moisture, combustible matter and ash.

A boiler trial should be carried out over at least 8 hours, and wherever possible the duration should be 12 hours; the longer the test the smaller being the errors.

Readings of all thermometers, meters, etc., should be taken at quarter-hourly intervals, with the exception, perhaps, of the CO_2 tests, where half-hourly readings will be usually sufficient, with intermediate analysis, if thought necessary, when variations occur in the conditions of firing, draught, etc.

A very useful water-measuring plant is a small flow recorder and meter of the weir and notch type, mounted complete upon a trolley with a small electrically driven turbine or three-throw pump. A recorder of this type will obviate readings being taken, and, indeed, if a complete set of accurate recording apparatus, calibrated before and after the trial, is available, the human assistance may be reduced to a minimum. With such recorders for temperatures, CO_2, pressure and draught, and also distance pyrometers of the electric thermo-couple type with indicators in the stokehold, it is possible for one engineer to run the test single-handed; apart, of course, from the actual firing of the boiler.

The results of the test should be set out in the form shown on pages 153–155.

Readings taken of TEST OF BOILER NO.______ *Date*______ TEST CARRIED OUT BY______

TIME.	COAL.		FEED WATER.					STEAM.			DRAUGHT.				GASES.			FIRES.		NOTES.
			WATER METER			TEMP. °F.									TEMP.					
	Quantity Fired.	TOTAL.	Reading.	Difference.	TOTAL.	Econʳ. Inlet.	Econʳ. Outlet.	Pressure.	Temperature.	Moisture.	Over Fires.	Downtake.	At Dampers.	At Chimney.	Leaving Boiler.	Leaving Econʳ.	% CO_2.	Stoker Speed.	Fire Thickness.	

GENERAL REMARKS:

Signature :______

DATA OBTAINED FROM TEST OF

BOILER No. ______. Date ______, 19__.
Test carried out by—
Duration of test— hrs. mins.
Heating-surface of boiler— sq. ft. Grate Area— sq. ft.
Method of firing—
Heating-surface of superheater— sq. ft.
" " " economiser— " "

Coal.—
Calorific value— B.Th.U. dry.
" " " as fired.
Analysis: Moisture %, Vol. %. Fixed carbon %. Ash %.
Name and description of coal—
Price per ton—
Total coal consumed— tons cwt. qrs. lbs. (= lbs.).
Total ashes removed— " " " (= ").
Average coal consumed per hour— lbs.

Water.—
Total evaporated by meter— galls.
Average temperature at Economiser Inlet— °F.
" " " Outlet— °F.
Average evaporation per hour— lbs. (actual).
Evaporation per lb. of coal consumed— lbs. (actual).

Steam.—
Average pressure by gauge— lbs. per sq. in.
" temperature of saturated steam— °F.
" temperature of superheated steam— °F.
" degrees of superheat— °F.
Factor of Evaporation—
Specific heat of superheated steam—

Draught.—
(Averages)—
Over fires— in. At Downtake— in. At Dampers— in. At Stack— in.

Gases.—
Average temperature leaving Boiler— °F.
" " " Economiser— °F.
" CO_2 %; O %; CO %.

Fires.—
Average thickness— ins.
" stoker speed.

CURRENT CONSUMPTION OF MOTORS:—
Stoker— units. Fan— units. Pump— units. Economiser— units. Total— units.
Equivalent heat value— B.Th.U.
Signature ________________,

RESULT OF BOILER TRIAL

Date ________, 19__.

BOILER No. ______. Type—

Ratio of heating surface to grate area— : 1

Coal consumed per sq. ft. of grate per hour— lbs.

Water evaporated per sq. ft. of heating surface per hour— lbs. (actual)

Water evaporated per sq. ft. of heating surface per hour— lbs. (from and at 212° F.).

Average water evaporated per hour— lbs. (from and at 212 ° F.).

Water evaporated per lb. of coal consumed— lbs. (from and at 212° F.).

Thermal efficiency of Boiler and Superheater— %.

,, ,, ,, ,, Economiser— %.

	FIRES.	
	Thickness.	Stoker Speed.
Maximum evaporation per hour—		
Average ,, ,,		
Highest percentage CO_2 (draught in)		
,, ,, CO_2 (draught in.)		
Lowest gas temperatures—		
Best average conditions as above—		
Evaporation— lbs.; % CO_2; draught in.		

Percentage of ashes removed to coal consumed— %.

Approximate combustible content of ashes— %.

Cost of evaporating 1000 lbs. of water *s.* *d.* actual.

,, ,, ,, ,, *s.* *d.* from and at 212° F.

Losses—

Moisture— %, Ashes— %, Gases— %.

Signature ____________.

In order to understand clearly the various stages of carrying out an efficiency trial and how the ultimate results are obtained, we may classify the various data under the following principal heads, viz.—

I. Heat value of coal fired,
II. Amount of heat in feed water,
III. „ „ delivered in dry steam,
IV. „ „ lost by way of chimney,
V. „ „ lost in ashes,
VI. „ „ lost as moisture in steam,
VII. „ „ lost by radiation and otherwise unaccounted for,

and will now describe the methods of determining the above main factors in the order given.

I. Heat Value of the Coal Fired

The coal sample is tested in the laboratory for calorific value, which gives the total heat in B.Th.U. per lb. of coal burnt.

If the calorific value is divided by the latent heat or heat required to evaporate 1 lb. of water at 212° F., we obtain the "evaporative power" of the fuel.

The evaporative power of a fuel is the quantity of water that would be evaporated from and at 212° F. with a boiler working at 100 % efficiency. This degree of efficiency, of course, is unobtainable in practice, and therefore the efficiency shown by a boiler test is obtainable from the following formula—

$$E = \frac{A \times 100}{\frac{C}{970{\cdot}4}} \text{ per cent.}$$

Where E = Thermal efficiency of boiler plant.
C = Calorific value of fuel in B.Th.U. per lb.
A = Evaporation per lb. of fuel "from and at" 212° F.

The total weight of coal fired is obtained by ordinary weighing, the total heat being represented by

Calorific value × total weight in lbs.

In order to avoid the use of figures of unwieldy size the evaporation in lbs. of water per lb. of coal fired is first calculated, and the thermal efficiency obtained from this.

II. Heat in Feed Water

The water fed into the boiler will contain a certain quantity of heat which has to be subtracted from the total heat of the steam delivered when calculating the amount of heat transference.

The total heat per lb. of water at a required temperature will be found in the Water Table in the Appendix.

By taking readings of the temperature of the feed water at both inlet and outlet of the economiser, together with the water meter reading, we have the necessary factors for calculating the heat abstracted from the gases by the economiser, and the total heat per lb. of water entering the boiler.

III. Heat in Dry Steam

For dry saturated steam the heat per lb. is found by comparing the average steam pressure during the test with the Steam Tables, from which the total heat will be found quite readily.

But as saturated steam always contains more or less suspended moisture, regular tests must be made and the percentage moisture, as determined, subtracted from the evaporation.

With superheated steam, in addition to readings being taken of the pressure, the average temperature is also required.

By subtracting the temperature of saturated steam at the average pressure observed from the average temperature of the superheated steam, the number of degrees of superheat is obtained.

The total heat ~~per lb.~~ of steam delivered is then obtained as follows—

$$H = h + (s \times d)$$

Where H = total heat of steam delivered.
h = total heat in 1 lb. of dry steam at observed pressure.
s = superheat in °F.
d = specific heat of superheated steam.

The factor d is found in the Table of Specific Heat of Superheated Steam in the Appendix.

We have now all the necessary data for calculating the thermal efficiency of the complete plant or any individual portion of it.

The formula used for saturated steam is as follows—

$$E = \frac{W(H - h) \times 100}{c}$$

Where E = Thermal efficiency in per cent.

W = Water evaporated per lb. of coal (actual).

H = Total heat in 1 lb. of steam at observed pressure.

h = Total heat in 1 lb. of water at observed temperature.

c = Calorific value of fuel in B.Th.U. per lb.

The factor W is the total quantity of water fed into the boiler *less* the percentage of moisture obtained by a calorimeter test of the steam dryness.

For superheated steam the amount of heat added to the steam in the superheater has to be taken into account, the formula being then as follows—

$$E = \frac{W(H - h + h_1) \times 100}{c}$$

Where h_1 is the amount of heat added per lb. of steam by superheating.

W is the evaporation per lb. of coal without deductions.

The above results will give all the information necessary for determining whether the boiler is fulfilling its guarantee or otherwise giving a satisfactory result as regards efficiency.

The other data mentioned are required in order to find out in what directions the lost heat, represented by the balance of the 100 %, is dissipated; and the application of these will now be considered.

IV. Chimney Losses

The heat lost to the atmosphere by way of the chimney is obtained by a calculation based upon the amount of CO_2 present in conjunction with the temperature of the gases.

We have already seen that, under natural draught conditions, a chimney base temperature of 500° F. is the minimum necessary to maintain a sufficient draught for ensuring ample air supply to the furnace.

With 12 % of CO_2 in the flue gases, this represents a loss of 14 % of the heat of the fuel.

The loss incurred with various percentages of CO_2 and gas temperatures can be found by referring to the chart, Fig. 97.

Where induced draught and forced draught fans are employed the power consumption of these should be reduced to the equivalent B.Th.U.s and calculated as chimney loss. This is a point that is frequently overlooked, and consequently gives a partly fictitious increase of efficiency with mechanical as against natural draught.

If we obtain the electrical units (kilowatt-hours) consumed by the fan motors, the equivalent chimney loss is represented by this formula—

$$L = KWH \times 3440$$

where

L = Heat in B.Th.U.s.
K.W.H. = Kilowatt-hours or electrical units (B.T.U.).
3440 = B.Th.U. per kilowatt-hour.

With steam-driven fans the steam consumption is calculated from indicator diagrams in the usual way, the heat loss being obtained from the Steam Tables.

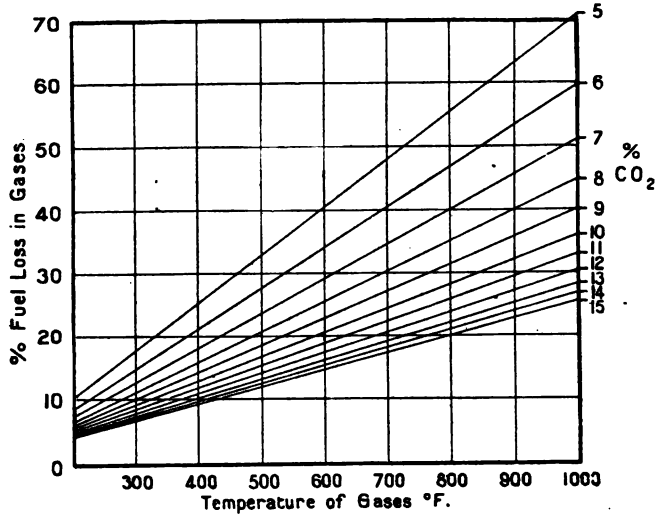


FIG. 97.—Chart showing Loss in Flue Gases.

As regards steam jets for forced or induced draught, the consumption of these is somewhat difficult to measure, but could be roughly estimated by a small steam-flow meter or Venturi tube device. It has been stated that these jets will account for 5 % of the total output of steam generated in the boiler, and if this is the case the installation of a rotary fan blower should be considered wherever this is practicable.

V. HEAT LOSS IN ASHES

For all practical purposes the heat lost in the ashes by unconsumed fuel may be obtained by testing a dried sample of the ashes removed for combustible matter and ash. The combustible matter will be mainly carbon, and the percentage of combustible matter calculated to be in the ashes removed × 14,500 will give the total heat loss due to unburnt carbon. The heat of the ashes is difficult to determine, owing to the practical impossibility of measuring their temperature as removed from the furnace, together with the uncertainty of the specific heat. Ash may consist of so many different substances in infinitely varying proportions that the specific heat of a sample can only be determined after accurate "ultimate analysis."

VI. Heat Lost in Moisture in Steam

This factor of loss is obtained by calorimeter test, and is, of course, only required when carrying out a trial without superheaters.

VII. Heat Loss by Radiation and otherwise unaccounted for

After calculation of the sources of loss already mentioned, there remains a balance which cannot be definitely assigned to any cause and is set down under this head.

Heat Balance Sheet

In setting out the final results of a complete boiler trial it is customary in modern practice to adopt the form of a balance sheet. On one side is shown the expenditure in B.Th.U.s per lb. of coal representing 100 %, and on the other side of the sheet is shown in detail the various methods of recovery in the different units of the complete plant and the sources of loss in B.Th.U.s and percentages of the total.

As pointed out before, a moisture test is not necessary where a superheater forms part of the plant.

HEAT BALANCE

Trial of Boiler No.__________ *Date*__________

	B.Th.U.	%		B.Th.U.	%
To calorific value of coal . . .		100	To heat transfer in boiler . . .		
„ power consumption of fans .			„ „ „ superheater .		
			„ „ „ economiser .		
			„ „ „ combined plant.		
			To loss in flue gases		
			„ „ by moisture		
			„ „ in ashes		
			„ „ by radiation and unaccounted for		
					100

Possible Sources of Error

Many boiler trials have been carried out which are quite worthless, though this may not be known to the parties concerned.

In order that such tests may be of value certain precautions must be taken to ensure that at the end of the test the data obtained are perfectly trustworthy, and, as such, quite reliable as a guide to correct conclusions.

Before commencing a test the engineer in charge must satisfy himself that there is no leakage of water taking place. The blow-down valve should especially have attention in this respect. The blow-off pipe should be broken at a joint on the outlet side of the valve to make quite certain that this is not passing water. Other places such as superheater drains, economiser blow-off and safety valves, etc., should have similar attention. Small leakages such as from water-gauge cocks, water-sampling valves, etc., should be measured from time to time throughout the test, and the water lost from these causes subtracted from the total amount registered by the water meter.

A test of a boiler and superheater is often rendered practically useless by allowing the safety valve to blow off for a more or less considerable proportion of the time. If the whole of the water fed into the boiler is calculated as superheated steam, the efficiency will appear to be considerably higher than is actually the case, the safety-valve discharge being saturated steam with no superheat.

Blowing of safety valves does not affect the accuracy of a test involving saturated steam only.

The water-gauge glass should have the water level carefully marked at the commencement of the trial by a piece of string tied around the gauge tube, and the feed must be carefully regulated towards the end of the test so that the water in the glass stands at exactly the same position as at the commencement.

General Instructions for conducting a Boiler Trial

Start firing the boiler with the same class of coal that is to be used during the test at least one hour before commencing.

Have an ample supply of coal weighed out ready before starting time.

See that all thermometer cups have sufficient mercury in them to properly immerse the bulbs.

See that all thermometers and other instruments are well lighted and their scales readily decipherable.

Make suitable preparations for refreshment and relief of the various assistants employed.

With mechanical stokers level off the coal in the hoppers and mark the height at the commencement of the trial.

Also mark the water level, as before described, by means of a string tied round the gauge glass.

Take readings of all gauges, thermometers and pyrometers quarter-hourly.

Enter water evaporation half-hourly.

Take CO_2 readings half-hourly.

Enter readings on sheet as shown on p. 153.

Working out of Tests

As the feed temperature during different trials may vary within more or less wide limits, it is the correct practice to work out all figures of evaporation per lb. of fuel, evaporation per hour, etc., also cost of evaporating 10,000 lbs. of water, showing what would have been the result had the water been fed in at 212° F. and evaporated at that temperature.

This will give a fair basis of comparison between different trials and fuels.

The evaporation actually obtained is multiplied by a factor which varies with the feed temperature, steam pressure and amount of superheat, and can be obtained from the Table of Factors of Evaporation in the Appendix.

The efficiency of the boiler shown during the trial is calculated from either the actual evaporation, or from the evaporation "from and at" 212° F. divided by the evaporative power of the fuel, and the whole multiplied by 100.

To obtain the "factor of evaporation" the following formula may be applied—

$$F = \frac{H - h + h_1}{970\ 4}$$

Where—

F = Factor of evaporation.
H = Total heat in saturated steam.
h = Total heat in feed water.
h_1 = Heat added to steam in superheater.

The evaporation of water per lb. of coal "from and at" 212° F. is then—

$$E = F \times W$$

where—

E = evaporation "from and at" 212° F.
F = factor of evaporation.
W = water evaporated per lb. of coal (actual).

To obtain the cost of evaporating 10,000 lbs. of water the following formula may be used—

$$\text{Cost in shillings per 10,000 lbs.} = \frac{P \times \frac{10{,}000}{E}}{2240}$$

Where P = Price of coal per ton in shillings.
E = Evaporation per lb. of coal "from and at" 212° F.

Boiler trials are valuable as a means of ascertaining the quality of the coal as compared with that originally supplied, for a mere laboratory test as a rule is of little use as a guide to what results the coal will give under practical conditions. Nevertheless the laboratory tests should be a regular feature at all times, as an immediate indication will then be provided of any change in the quality of the coal supplied, together with being a suitable means of deciding when a complete trial under working conditions should be made.

CHAPTER XIV

Maintenance of Boiler Plants.—Cleaning, internally and in the flues —Care of mountings—Suction dust-removal plant for boiler flues —Pneumatic, hydraulic and steam-scaling hammers and tube cleaners —Hydraulic tests—Housing of boiler plants—Mountings and lighting.

In order that the best results may be obtained from any boiler plant, it is essential that the greatest care and attention must be bestowed upon the cleanliness of all the units of the plant, also that all mountings are operating in a correct manner.

To attain this end, the incidence of all cleaning operations should be based upon certain definite periods of working, and unless this is done in a thoroughly systematic manner the maintenance of uniformly satisfactory results will not be attained.

In view of the above a careful daily record should be kept of the hours run of the various items of the plant, viz.—

Boilers and superheaters.
Economisers.
Feed-Water Heaters.
Feed Pumps.

Even with the best feed water procurable, the practice of merely cleaning boilers and economisers once annually to meet the requirements of the Home Office Regulations is most wasteful, for however thoroughly the cleaning may be carried out at the time this does not prevent the formation of scale taking place rapidly.

The correct interval between successive internal cleanings will vary within wide limits, this being determined by the nature of the feed water used and working conditions generally.

The maximum and minimum intervals are given here, the final determination depending upon the results obtained in each individual plant.

Table VI

Type of Boiler, etc.	Maximum Interval with Good Water.	Maximum Interval with Bad Water.
Lancashire	1500 hrs. run	800 hrs. run
Water Tube . . .	1000 ,,	500 ,,
Multitubular . . .	1100 ,,	600 ,,
Economisers . . .	1000 ,,	500 ,,
Feed-Water Heaters .	1000 ,,	500 ,,

Wherever possible the flues of all types of boilers should be cleaned out at least once per working week. Economisers, owing to the large soot chamber capacity provided, should have their flues cleaned about once per fortnight.

The author is aware that the system set out above is not adhered to by a very long way in most manufacturing concerns, but it is only by proper attention to such matters that any material impression will be made upon the fuel bill. Maintenance of reasonable cleanliness in boiler plant will repay the additional expenditure many times over in the course of the year.

In innumerable cases the dirty state of boilers is the sole and only cause of the following uneconomical conditions of working, viz.—

Shortage of draught and insufficient air supply;
Reduced steaming capacity;
Reduced efficiency and economy;

caused by choked flues and fouled heating surfaces.

BOILER AND ECONOMISER FLUE CLEANING

The ordinary method of cleaning flues by hand without the use of special appliances is open to many objections.

Firstly, the boiler has to be cooled off for this operation to be carried out, not only entailing a loss of time, which in some cases is not permissible, but also a considerable amount of the heat in the boiler is lost by way of the flues in the cooling-off process.

A method of getting over this difficulty which has been adopted in most modern power-houses is to provide a basement beneath the boilers, and by building the soot chambers with hoppered floors the flue dust can be removed by opening a door or shutter in the basement and extracting it by gravity. Similar arrangements are also adopted with economiser soot chambers.

It would seem that there are no insuperable obstacles in the way of applying similar methods to Lancashire boilers, although the flues would have to be built in a series of hoppers.

With water-tube boilers the flue dust is usually blown off the tubes while the boilers are working by means of steam or, preferably, compressed air jets. This operation should be part of a daily routine.

Another matter in connection with the cleaning of water-tube boilers externally is the accumulation of a mass of light clinkers upon the tube surfaces facing the fires. This, of course, should be regularly removed by the aid of suitable steel scrapers, made with a curved edge to fit the curve of the tube.

Apart from offering a resistance to the passage of heat, this clinker, owing to its formation in patches, is frequently the cause of blistered and burst tubes. The hot gases coming into contact with the refractory material (clinker) cause it to become incandescent with intense local heat. Increased scale formation will take place at these places with eventual overheating, bulging and bursting of the tubes.

For the rapid removal of dust from flues a very convenient apparatus is obtainable and known as the "Imperia" dust remover. It consists of a receiver of sheet steel from which the air is exhausted by means of a steam-jet ejector. The receiver is connected by means of any convenient system of pipes and unions to a flexible armoured hose-pipe which is fitted with a special non-choking nozzle. By feeding the nozzle into the flues by means of a rod the flue dust is extracted by suction. On passing into the receiver the velocity of the dust is decreased, and this, being damped by a spray, is deposited in the bottom. The receiver may be mounted on a steel frame structure over the ash siding or roadway, so that it may be discharged direct into a railway wagon or cart, as the case may be.

By providing suitable openings under the fire-bridges and into the front ends of the flues, Lancashire boilers may be readily cleared of flue dust without the necessity of men entering the flues or of cooling the boiler down. A somewhat similar appliance is manufactured by Messrs. Ed. Bennis, who use a rotary blower instead of a steam jet for exhausting the receiver.

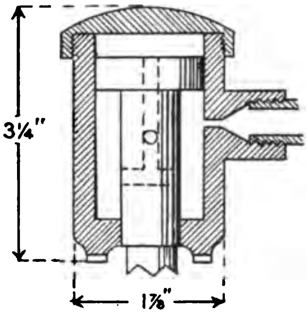


FIG. 98.—Pneumatic Scaling Hammer.

For removing the scale from the internal surfaces of boilers the most rapid method is by means of the pneumatic scaling-hammer shown in section in Fig. 98. These hammers are supplied by several different manufacturers, and should not exceed the dimensions shown, as otherwise they will be too heavy to handle for any length of time.

In the light of modern practice a compressed air supply is an indispensable adjunct to a boiler plant, therefore a compressed air service should always be included when designing new plants. As compressed air has so many uses in other directions, especially for portable tools such as drilling machines, etc., it should find a place in every engineering works. There are many firms specialising in air-compressors, both portable and as fixtures, and to these the reader is referred for advice as to suitable designs and capacities.

For cleaning the tubes of water-tube boilers, the only satisfactory apparatus is the turbine cleaner, operated either pneumatically or by hydraulic or steam power.

Examples of turbine tube-cleaners are shown in Figs. 99, 100 and 101, the first being a hydraulic turbine with cutter suitable for normal scale; Fig. 100 is a cutter for use on hard scale, and is shown fitted to a pneumatic turbine; Fig. 101 shows a special cutter head for dealing with very hard and dense scale, and which may be driven by either steam or air power, or may be also used with an electric motor in conjunction with a flexible shaft.

The machines as shown in the illustrations are only suitable for straight tubes, but special turbines are constructed for use in curved tubes, except the cutter shown in Fig. 101.

If the feed water has been correctly treated, it should be quite possible to clean the tubes satisfactorily by means of a circular steel wire brush with flat bristles, without recourse to mechanical means.

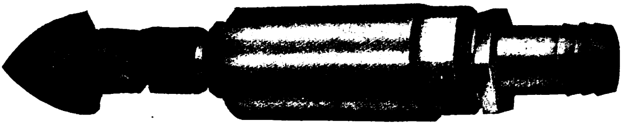


Fig. 99.

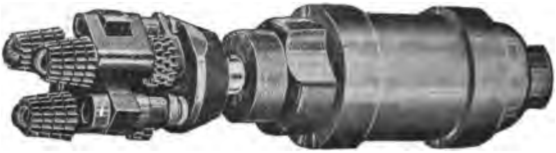


Fig. 100.

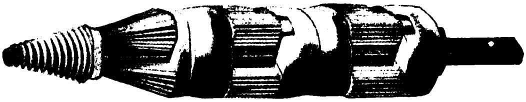


Fig. 101.
Turbine Tube Cleaners.

With multitubular boilers such as the locomotive or marine types a wire brush is generally used for cleaning the tubes when at rest, but by some such means as described below the tubes may be readily cleaned while the boiler is at work, thus obviating cooling-off losses.

There are various arrangements of steam blowers suitable for removing the soot from tubular boilers while these are at work, one notable example being Parry's Steam Blower. This consists of a steam jet so arranged that it can be rotated from the outside of the combustion chamber by hand, and designed to blow through every tube in turn. Although this is very effective indeed, it should not displace a regular brushing-through once per week wherever possible.

Before finally setting a new boiler to work, it should be filled to working-level and a bucketful of soda ash added. Close up the boiler and light the fires and raise a few pounds pressure in the boiler, keeping it thus for a few hours. Then let the fires out, cool off and empty the boiler of water. The manholes are again uncovered and the accumulation of iron scale, dirt and oily sludge is removed, finishing the process by a thorough swilling out with a hose-pipe. This precaution is particularly necessary with water-tube and multitubular boilers where there is certainty of the presence of oil due to the lubrication of the expanding tools used in fitting the tubes.

When a boiler is laid off for the annual examination as required by the Factories Act, the opportunity should be taken of removing all the mountings and overhauling them thoroughly.

Some provision should be made for testing the safety, blow-down, feed and isolating valves under working pressure so that the engineer in charge is perfectly satisfied that these are all in proper order as to steam and water tightness before refitting them to the boiler.

Safety valves should lift at 5 % above working pressure, and a smaller margin than this is apt to lead to considerable waste from blowing off, especially where the load is subject to large and sudden variations.

The high and low water valve should be carefully adjusted so as not to lift too soon for the same reasons, but the limit must not be cut too fine or there will be danger of overheating of the surfaces which the valve is provided to protect.

Tubular boilers should always be tested by hydraulic pressure before lighting up at the normal pressure at which the boiler works so that any leakage at the expanded joints may be detected, and the tubes re-expanded if found necessary.

As regards re-expanding water tubes, it is usually found that after this has once been carried out its repetition at a later date is, as a rule, useless owing to the metal having become inelastic, and therefore it is as well to renew any tube that is found to be leaking at the expanded joint at once if this has already been re-expanded at some previous date. If this is not done there is danger of the tube cracking owing to the brittle condition of the metal.

Housing of Boiler Plants

This very important question does not always receive the attention that it should have paid to it.

Boilers should never be installed in the open air.

Boilers should be sufficiently enclosed so that the temperature is no lower than that required for the comfort of the attendants.

Where coal is unloaded direct into bunkers on the firing-floor level, only sufficient room should be provided for a wagon to enter the boiler-house, the opening being closed by a suitable door or screen when not in use.

Openings in the walls of boiler-houses should always be glazed in order to prevent currents of cold air from entering and aggravating the radiation losses.

Ample room should be provided in front of the boilers for the firemen to handle rakes, slices, shovels and other tools.

A platform should be constructed in front of the larger boilers wherever required for the fireman to have a proper command of his fire-grate. With 9 ft. diameter Lancashire boilers the fire-grate cannot be attended to effectively from the ordinary floor level.

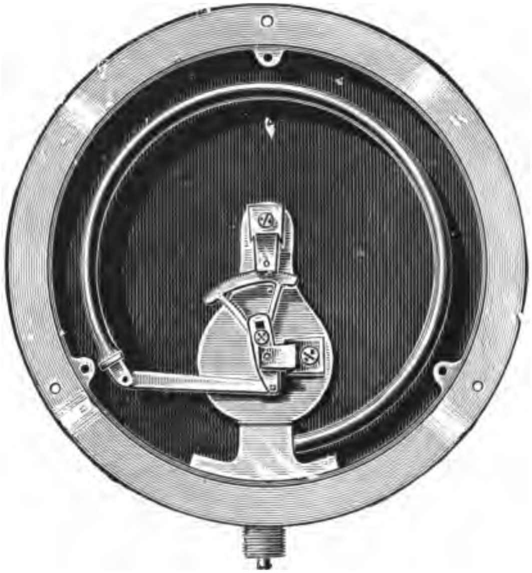


Fig. 102.—Dewrance's Pressure-gauge Movement.

Cleanliness will always assist towards better operation, therefore anything tending to the production of dust and dirt should be avoided.

Some forms of coal-measuring devices in connection with overhead bunkers are very objectionable in respect to their tendency to distribute dust, especially where "nut" coal is in use. At each discharge of the measuring gear in the coal chute clouds of coal dust arise which keep the boiler house in a continual state of dirt.

MAINTENANCE OF FEED PUMPS

Reciprocating pumps are particularly liable to be very wasteful in steam unless both the steam and water ends are properly cared for. Pumps should be thoroughly overhauled at regular intervals and the steam ends should have indicator cards taken to check the steam consumption. If the plungers and the water valves are not perfectly tight a great loss of steam will ensue owing to the increased speed at which the pump has to work to maintain the supply.

See that the water valves are skimmed up and ground on to their seatings at the end of definite periods of running, at the same time examining the plunger rings and steam valve gear and piston rings. An open-ended connection to the exhaust is a useful provision, the examination of which now and again serves as a rough guide to the state of the steam end of the pump. Steam pumps should exhaust into a feed heater in the ordinary course of events, so this open end should only be used occasionally as described above.

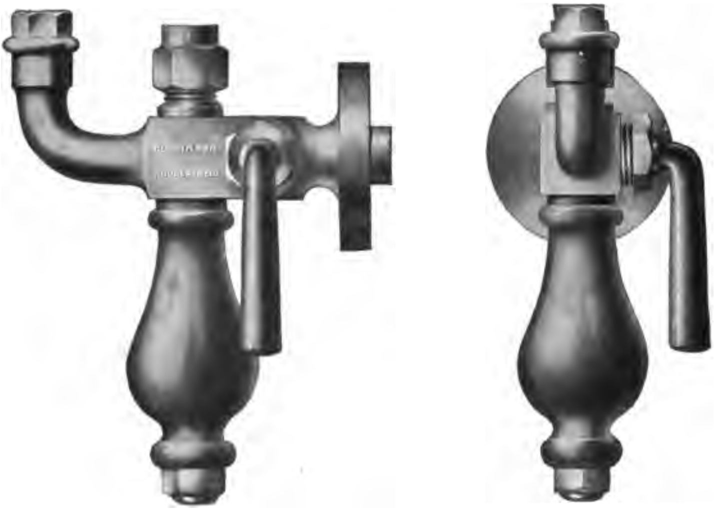


FIG. 103.—Hopkinson's Pressure-gauge Syphon.

Boiler Mountings

The essential mountings required on a boiler are as follows—

1. Steam Pressure Gauge.
2. Feed Valves.
3. Water Gauges.
4. Safety Valves.
5. Blow-down Cock or Valve.
6. Stop Valve and Isolating Valve.

1. *The Steam Pressure Gauge*

The mechanism of the ordinary Bourdon pressure gauge is seen in Fig. 102, and consists of a circular piece of solid drawn bronze tube of oval section one end to which the pressure is applied, the other end being hermetically sealed. On application of pressure within the tube, this tends to straighten itself out, the degree of movement depending upon the amount of pressure applied. The motion of the tube is conveyed by means of a quadrant and pinion arrangement to the centre pivot of the pointer which works over a graduated scale. The illustration is of a movement manufactured by Messrs. Dewrance & Co.

Direct steam pressure must never be applied direct to a gauge, but a "syphon". or condenser should intervene so as to ensure that only cold water actually enters the instrument. A compact syphon complete with plug cock and test-gauge connection is shown in Fig. 103. The steam pipe dips into the bulb-shaped reservoir at the bottom and the pressure gauge is mounted at the top. The cock is a three-way one, connecting either to the test gauge or the regular working gauge or may be used to shut both off at once. This fitting is of Messrs. Hopkinson's manufacture.

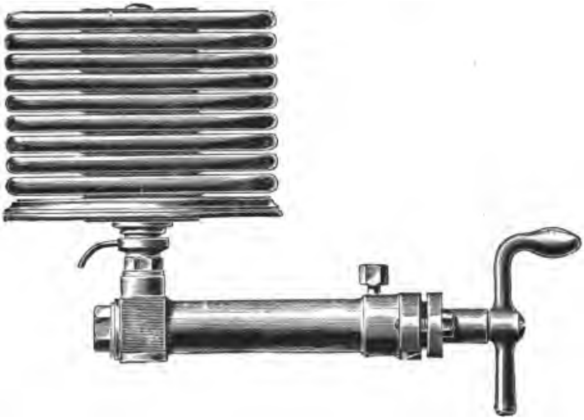


FIG. 104.—Dewrance's Pressure-gauge Tester.

As all engineers are aware, steam gauges do not remain accurate for very long periods, there being a general tendency to read high as time passes. The importance of steam pressure as a factor in economy has already been mentioned; reliance upon a boiler gauge that has not been recently tested will often lead to safety valves being set to blow off at too low a pressure owing to over registration of the steam gauge.

An accurate testing device is supplied by Messrs. Dewrance & Co. and utilises a set of dead weights acting upon an accurately

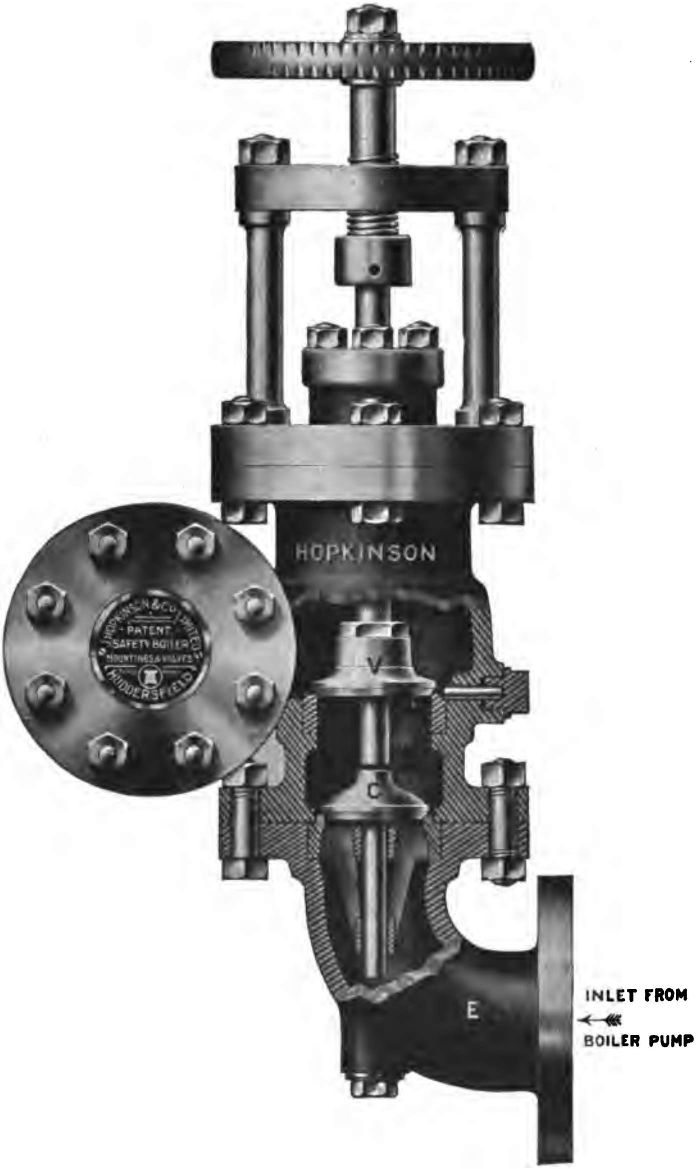


FIG. 105.—Hopkinson's Patent " Accessible " Feed-check Valve.

fitted plunger in the same chamber as that to which the gauge to be tested is attached, and which is filled with water. As seen in Fig. 104, the handle is used to apply pressure by screwing up, this pressure being determined absolutely by the weights used.

2. *Feed Valves*

These are always of the non-return or check pattern, that is to say, the valve is not attached to the spindle, but is held down upon its seat by the pressure in the boiler until the pressure beneath (from the feed main) is sufficient to lift it. The spindle screws down upon the valve either to hold it fast and out of action, or to release it to a varying degree as required by the water needed in the boiler.

Where two separate valves are used in series, one a direct stop valve and the other a loose or check valve, the stop valve must be located next to the boiler.

Hopkinson's Accessible Feed-check Valve (Fig. 105) combines the two valves in one body so that not only does the fixed valve V serve to shut off the check valve C from the boiler, but also by the extension of the spindle below V controls the lift of C as in the ordinary check valve.

By releasing the pressure in the feed main and closing valve V, the check valve C may be removed by merely disconnecting the special elbow E, without having to drop the pressure in the boiler.

There should always be additional valves or cocks between the feed main and the feed-check valves on each boiler so that the failure of one feed valve does not necessitate the shutting down of the whole plant. A great deal of waste in shutting down and starting up of boilers may be avoided by giving attention to these apparently insignificant details appertaining to ready accessibility.

3. *Water Gauges*

The illustration Fig. 106 shows the "Absolute" pattern of water-gauge fitting of Messrs. Hopkinson, which may be taken as a type of the best class of these mountings. The top and bottom fittings are both arranged to shut off automatically by means of the balls A and B, should the glass burst. The tube behind the glass is to provide a lifting movement to B when the glass bursts, the ball coming to rest and being held in position by the steam pressure as shown by the dotted outline.

A form of gauge glass that may be distinctly read from a considerable distance and does not require a protector is the "Klinger" or "Reflex" type. The glass is flat, very thick and vertically ribbed on the back or water side. The effect of the ribbed or prismatic back is that the water shows black against a white ground. Should the glass fracture it does not fly, but is held between the front and back portions of the fitting.

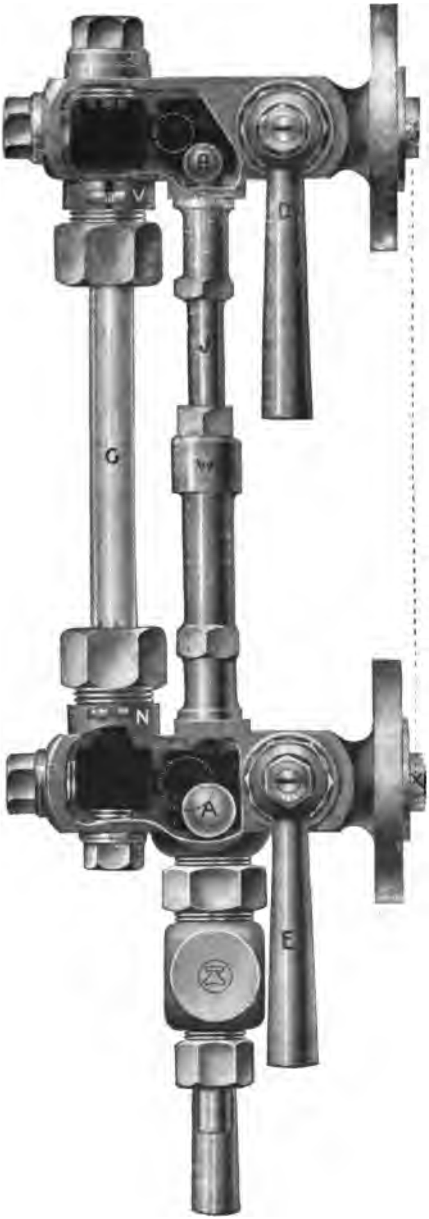


FIG. 106.—Hopkinson's Absolute Water Gauge.

All tubular gauges must be fitted with suitable protectors to reduce the danger to attendants and others from flying fragments of glass which might result in serious injuries.

4. *Safety Valves*

Safety valves for the relief of boilers from excessive pressure only, may be generally classified as follows—

(*a*) Spring-loaded,
(*b*) Dead-weight,
(*c*) Lever - weighted Valves.

(a) *Spring-loaded valves* for large boilers are usually of the "marine type," being a circular valve held down on to its seat by the direct pressure of a powerful spring, the compression of which is adjusted by a nut at the top.

Modern spring-loaded valves of this class are usually constructed with the valve portion larger than and overhanging the seating, so that directly the valve eases off the seating the steam acts upon an increased area and raises the valve further. This gives a much more rapid relief and also prevents the scoring of valve face and seating due to the wire drawing of steam between the two.

For smaller boilers the Ramsbottom spring-loaded valve is very suitable. The valve shown in Fig. 107 is of this type and is manufactured by Sir W. H. Bailey & Co. It consists of two vent pipes provided with valve seatings at their upper openings and connected at the bottom with the steam space of the boiler. A bridge-piece across the top of the two vent pipes serves to hold a valve on the seating of each of these, the tension being regulated by the spring between the two. The bridge-piece is extended to form a testing lever to ease the valves off their seats in order to ascertain whether they are working freely.

(b) *Dead-Weight Valves.*—One of the best forms of dead-weight valve is shown in Fig. 108, the "Ipsed" valve of Messrs. Hopkinson. This consists of a stand-pipe connected to the boiler steam space, at the top or escape opening of which a valve seating is fitted. A bell-shaped valve rests upon this, and is loaded by its being constructed to support the outer casing which contains the circular weights. The steam escapes around the stand-pipe and finds its exit by way of the flanged outlet shown at the right-hand side of the fitting.

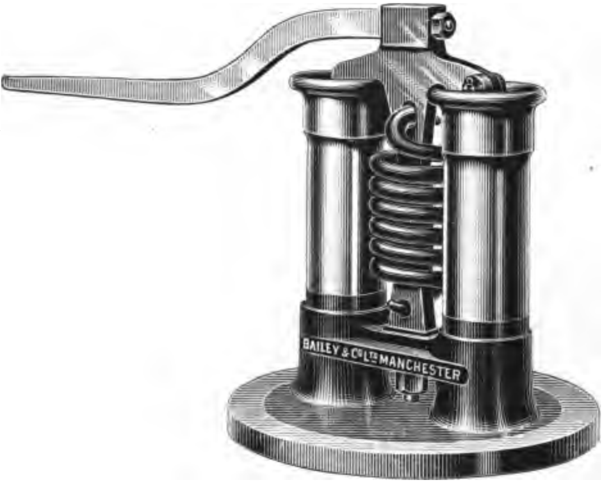


Fig. 107.—Ramsbottom Safety Valve.

In order to preserve the valves and seatings it is as well to turn dead-weight safety valves around a little way by hand at intervals.

(c) *Lever-Weighted Valves.*—These are only used as simple safety valves on smaller boilers, and consist merely of a mushroom valve held on to its seating by an external lever, at the end of which a weight is suspended.

Low-water Alarm Valves.—This is a type of valve which is constructed so as to give an indication either by means of a whistle or a small valve when the water has fallen so low in the boiler that immediate attention is required.

A modern example of this class of safety valve is the "Duad" valve of Messrs. Hopkinson (Fig. 109). It consists essentially of a lever-weighted safety valve which lifts with excessive steam pressure in the ordinary way.

In the centre of this "high steam" valve is another smaller valve which has a vertical and pendant stem to the bottom of which circular weights are hung. The whole of this arrangement completes the loading of the "high-steam" element.

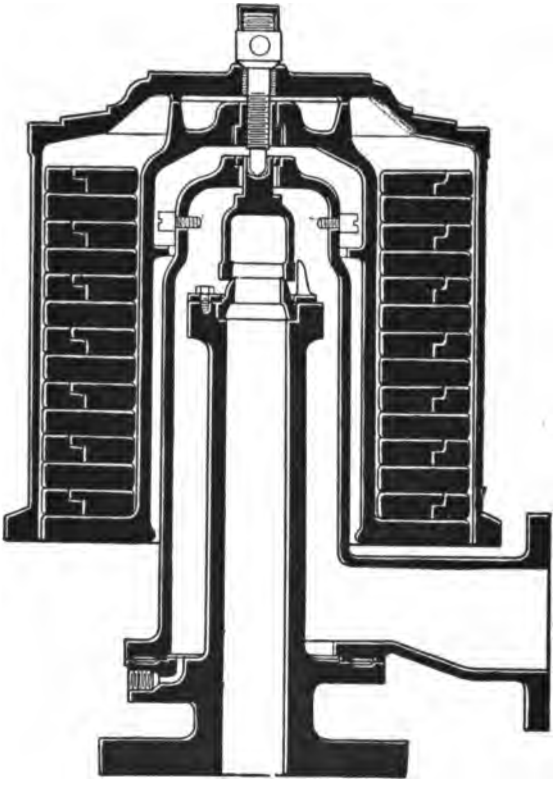


FIG. 108.—Hopkinson's "Ipsed" Dead-weight Safety Valve.

Within the boiler a lever is suspended, to one end of which is attached a vitrified stone float and at the other a metal counterweight. Where the lever passes beneath the centre of the valve it is made to encircle the valve stem, this circular portion having two projecting lugs which come into contact with the adjustable collar on the stem as the float falls.

The valve should be adjusted by holding the lever horizontal and adjusting the valve collar so that it just rests upon the two lugs on the lever. With the lever still horizontal the float should be adjusted in height as follows, viz.—

For Water-tube Boilers *bottom* of the float 2 ins. above the centre line of the lower water-gauge fitting.

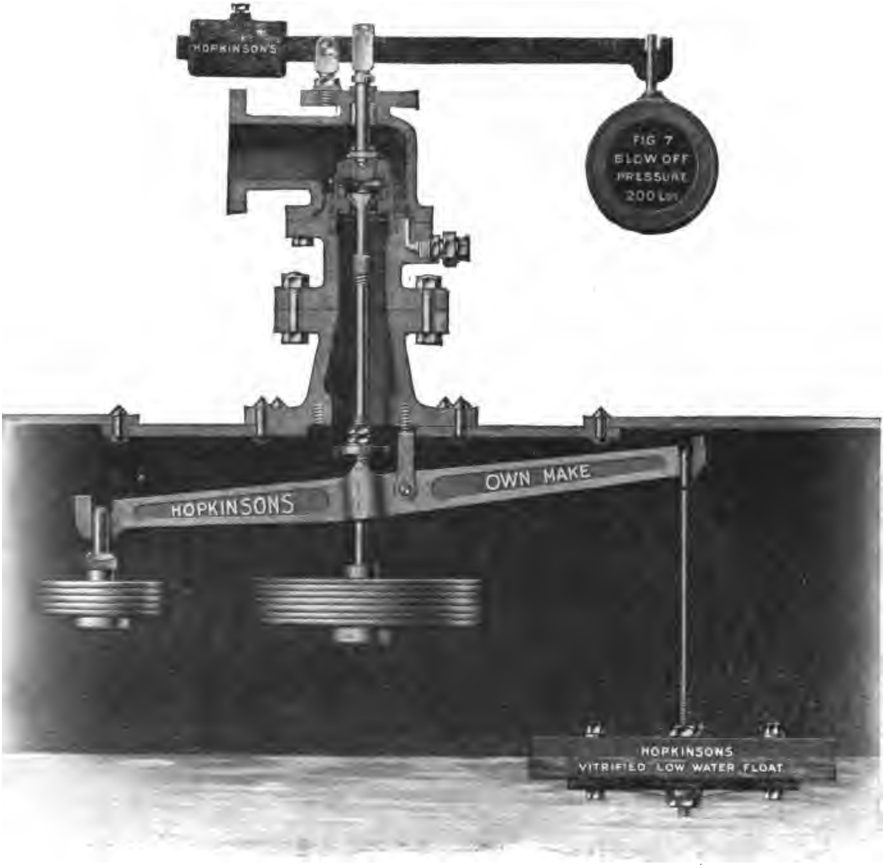


FIG. 109.—Hopkinson's "Duad" Low-water Valve.

For Lancashire Boilers *top* of the float 8 ins. above the crowns of the furnace and flue tubes.

A point that should be remembered in connection with these valves is that not only do they blow off at both high steam and low water, but also the "low-water" valve will sound if the water rises sufficiently high in the boiler to partially or entirely submerge the dead weight hanging from the valve spindle.

The sound emitted by the H and L water or "pilot" valve is quite distinct from and cannot be mistaken for that of the "high-steam" valve.

In many cases vent pipes, either of short length or perhaps carried upwards through the roof, are connected to safety valve outlets. The author finds that after being in use for some while the drains necessitated by this arrangement invariably get choked up with coal dust and other dirt, with the result that either the valve becomes water-logged by the condensation water in the vent pipe, or that the drains have to be disconnected and the water trickles over the boiler tops, permeating and spoiling the lagging and perhaps setting up dangerous external corrosion.

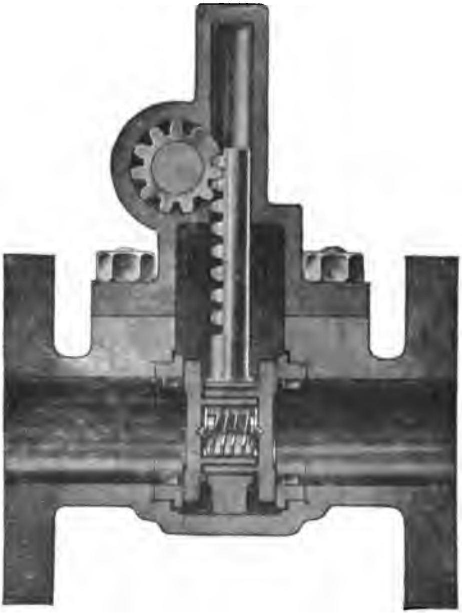


FIG. 110.—Hopkinson Blow-down Valve.

As blowing-off and leaky safety valves should be the exception, the correct remedy is to avoid this state of affairs as far as possible, and dispense with the use of vent pipes.

All safety valves on working boilers should be tested daily.

5. *Blow-down Cocks and Valves*

As regards blow-down cocks, since these are very apt to become leaky or to get stuck fast in their housings, they should never be used. The correct fitting for blowing off mud is a parallel slide valve of the rack-and-pinion type which gives a full-way opening with a three-quarter turn of the key. Such a valve by Messrs. Hopkinson is seen in section in Fig. 110. The square head of the pinion spindle is surrounded by a cage which permits of the entry only of the proper box key. There should only be one of these keys in the stokehold so that but one blow-down valve can be opened at a time, as the key can only be lifted from the valve when it is closed. This prevents any danger to men working in a boiler with the blow-down valve open, as this will have to be closed before the key can be removed to blow down another boiler. Additional precaution should be

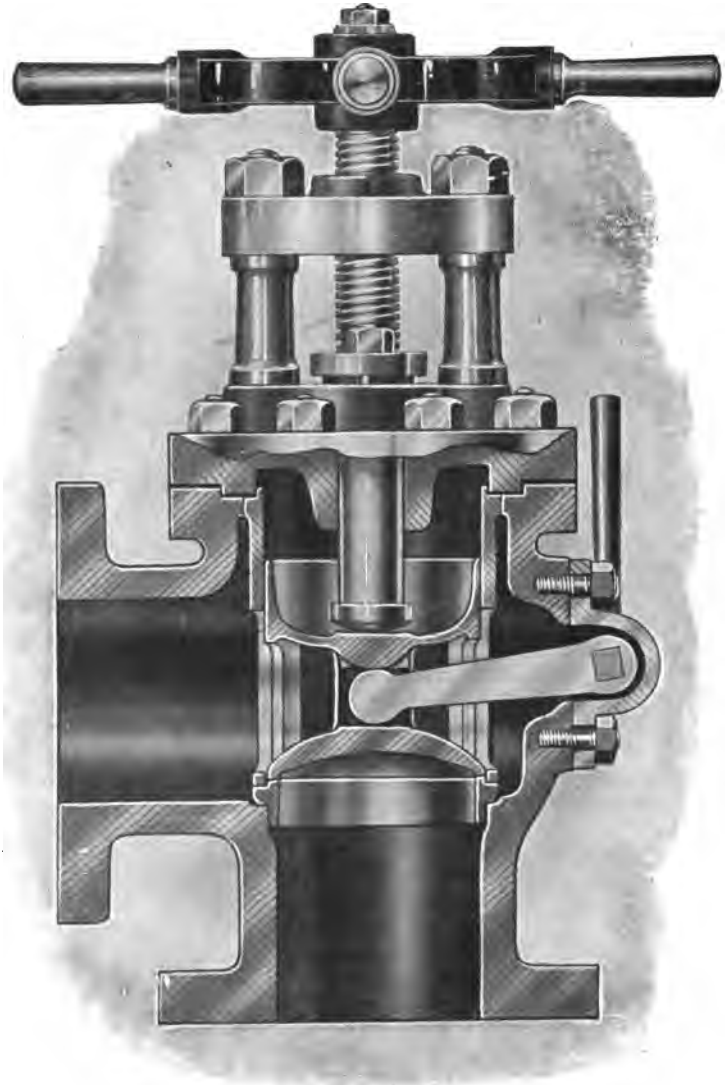


Fig. 111.—Dewrance's Isolating and Junction Valve.

taken against such accidents by fitting a reliable non-return valve on the blow-down branch of each boiler.

To let each boiler blow down through an open end into a much larger bore branch or the main blow-down pipe is practically useless as a safeguard against accidents, as when a boiler under pressure is blown down the boiling water and steam is certain to "back-up" any opening, and a man working near the boiler drain beneath the flues of, say, a Lancashire boiler under such circumstances has little or no chance of escaping fatal injuries of a particularly frightful nature.

6. *Stop Valves and Isolating Valves*

Boiler stop valves or junction valves may either be plain screw-down angle valves or loose valves of the non-return type.

Dewrance's patent vertical controlled isolating valve is shown in Fig. 111. The valve itself is in the form of a cylinder and piston. The valve spindle only serves to hold the valve in position when closed. The pressure in the boiler beneath the piston raises it, and should the boiler pressure fall below the pressure in the main the latter keeps the valve closed.

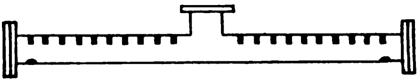


FIG. 112.—Anti-priming Pipe.

Every boiler should either have a combined valve fitted or else separate junction and isolating valves so that in the case of any failure such as burst tubes or collapsed furnaces the discharge of steam and water is limited to that contained in the faulty boiler and is not augmented by the whole steaming capacity of the remaining boilers in the battery.

In connection with stop valves it may not be out of place to refer to the anti-priming pipe within the boiler by which the steam is drawn off.

In its usual form (seen in Fig. 112) it consists of a horizontal cast-iron pipe suspended longitudinally within the boiler and as close to the crown of the shell or drum as practicable. On the upper side of this pipe slots are cut, and at either end (which is closed) a small hole of about ¾ in. diameter is provided at the underside to act as a drain. The steam is led away to the stop valve by a branch pipe in the centre. This forms the most efficient method of obtaining the driest possible steam.

FUSIBLE PLUGS

These consist of a brass casing (screwed into the furnace crown or other equivalent position in a boiler) containing a hollow brass plug secured within the casing by a belt or ring of special fusible alloy, which, on becoming overheated melts and allows the inner brass plug to be blown out by the pressure of steam, and to damp the fires before serious damage can occur.

LIGHTING OF BOILER-HOUSES, ETC.

Too much attention cannot be paid to the efficient lighting of the boiler-house generally, and also of the individual gauges, valves and other accessories.

Efficient work cannot be expected in an ill-lighted boiler-house, and serious consequences may easily result from badly illuminated water and steam gauges. Again, the danger to life and limb of the attendants who may need to operate valves over the boilers in partial or total darkness, is an ever-present possibility.

CHAPTER XV

Brickwork Settings of Boilers.—Arrangements—Baffling—Flue covers —Defects and methods of examination—Results of defective brickwork.

In dealing with the important subject of boiler brickwork it will be as well to review the different functions which its various applications serve.

The first purpose for which the brickwork is provided is to enclose and maintain the hot gases in intimate contact with the heating surfaces of the boiler. At the same time the brickwork must be sufficiently non-porous and carefully set so as to exclude any infiltration of air from the external atmosphere.

In cylindrical boilers of the Lancashire and kindred types, the weight of the boiler and its contents are supported upon brickwork. Water-tube boilers are in practically every case suspended upon a steel framework quite independent of any support from brickwork.

Brickwork is used in many types of boiler furnace as a refractory lining which becomes incandescent and ensures rapid gasification and ignition of the fuel upon the grate, which are the primary essentials of ultimate completeness of combustion.

In Lancashire, Water-tube and Cornish-type boilers the correct arrangement of the brickwork used to direct the gases upon their proper course is a matter that should always receive careful attention. A serious loss of efficiency may readily occur if a small or large proportion of the gases do not take their complete course through and around the boiler, owing to the internal leakiness of the brickwork permitting "short-cuts" between the furnace and dampers.

Brickwork of Lancashire and Cornish Boilers

In a plain furnace of this type the first brickwork met by the gases is the fire-bridge. This should not be more than 9 ins. thick and not exceed about 8 ins. height above the back of the grate, that is to say, a course one brick flat with one course of bricks on edge at the top. This top course should be bull-nosed both on the fire and flue sides, so as to avoid sharp angles which tend to retard the flow of the gases.

On reaching the back end of the flue tube the gases pass under the boiler by way of the downtake flue, and it is at this point where the most serious losses may occur through leaky brickwork and consequent short-circuiting. This leakage may take place direct into the main flue through cracks and fissures in the back wall of the downtake, but usually reaches its most serious proportions where the side walls meet the back end plate of the boiler. The longitudinal expansion of the boiler does not allow these side walls to be built hard against the back end plate, or the back wall of the downtake or even the outer wall of the main flue itself may be forced back and damaged. There is, therefore, always some small space between the back end plate and the side wall of the downtake which permits more or less short-circuiting to the dampers unless specially guarded against.

In Fig. 113 a method of sealing the gap in question is shown and is very effective. A channel about 2½ ins. deep by 2¼ ins. wide is cut in the dividing or side wall so that a length of woven asbestos rope, 2½ ins. in diameter, may be driven in between the brickwork and back end plate. A space of about ½ in. is left between the wall and end plate to allow for expansion, and the asbestos (which must not be caulked in hard) is sufficiently soft to squeeze up without moving the wall.

The seating blocks which divide the centre flue from the side flues do not, as a rule, leak to any serious extent, but nevertheless should always be kept gas-tight.

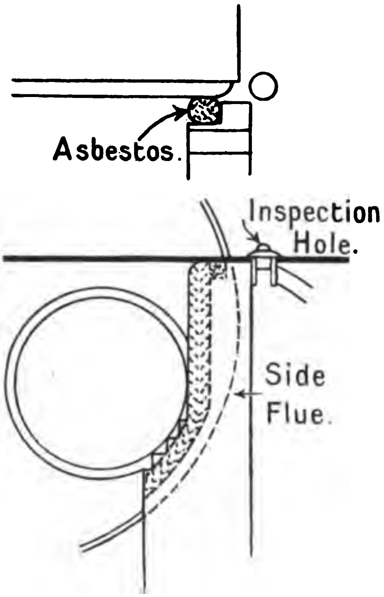


Fig. 113.—Asbestos Seal for back of Lancashire Boiler.

As the gases lose their luminosity and radiant properties in this bottom flue, and at the same time decrease in volume, a slight slope of the floor upwards towards the boiler front should be arranged so as to maintain the velocity of gas flow.

On reaching the front of the boiler the trouble most likely to be encountered is air leakage between the boiler shell and the front cross wall. This should be provided against by sealing the junction between the boiler shell and the brickwork with asbestos rope (as shown in Fig. 114) on the outside in a somewhat similar manner to the method used for the internal sealing already described. By continuing this asbestos seal along the side flue tops and across the back end plate (Fig. 115) little trouble will be encountered from air leakage in these positions.

The side flues should be as narrow as permissible consistent with sufficient room for the passage of a man through them, this provision being necessary for purposes of examination and cleaning.

In Chap. VI a method of roughly localising defects in brickwork and elsewhere by means of deductions from pyrometer, CO_2 and draught readings has been described. The definite location of such faults by direct observation will now be described.

Air leakage into the flues is best detected by passing the naked flame of a taper over every portion of the external brickwork and joints where such leakage may be present. Where air is leaking in to any appreciable amount the flame will be drawn inwards. Cracks in the brickwork should be pointed, leaky access doors should have asbestos gaskets fitted, and frames be refitted and pointed. The whole of the external walls of boiler, economiser and main flues should have three good coats of tar applied while the flues are hot, each coat being allowed to soak into the brickwork before the next is applied. This will effectively close all minute fissures and cracks.

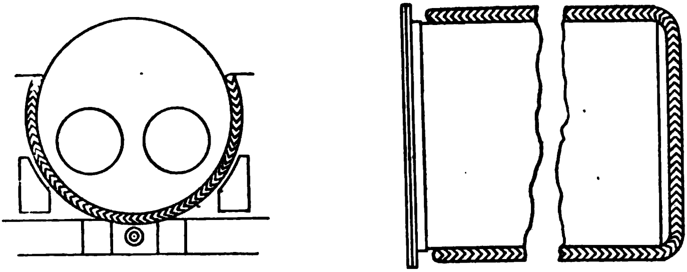


FIG. 114. FIG. 115.

Asbestos Sealing for Lancashire Boilers.

An effective and air-tight boiler side-flue cover is that supplied by Mr. Milner Hurd of Sheffield. As seen in Fig. 116, it consists of a reinforced concrete tile which is free to move radially outwards as indicated by the dotted line. Care should be taken that the radius of the tile is at right angles to the radius of the boiler shell at the point of contact. If the tile forms an obtuse angle with the boiler radius the side walls of the boiler are likely to be forced out. The levelling-up blocks serve the double purpose of providing a level top to the flue and also to seal the joints between the lower tiles. As the boiler expands the tile rises and at the same time raises the levelling-up block by the agency of the curved surface upon which the toe of the latter rests.

Passing now to examination for internal flue leakages, it is necessary to cool off the boiler and then stop up the front openings of the side flues. If the dampers are now opened and the full draught applied to the side flues any leakage or " short-circuiting " will be easily detected by a flame passed along the seatings and also at the back and side walls of the downtake. Any leakage discovered must be made good by means of pointing or asbestos rope packing as required.

Water-tube Boiler Brickwork

The high efficiency of water-tube boilers is to a very large extent dependent upon the air tightness of their external brickwork together with the good condition of the internal baffling.

The external walls are examined for leakage with a flame, and points that require particular attention are those where the ends of the drums pass through or are visible through the walls.

The leakages through the brickwork are dealt with by pointing and tarring, and the other leakages can be dealt with in a satisfactory manner by caulking with asbestos yarn or else adopting a system of asbestos rope in a similar way to that described for Lancashire boilers.

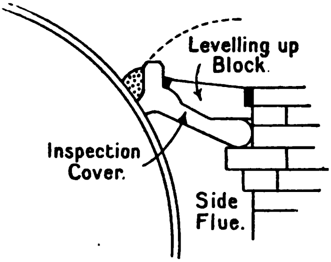


FIG. 116.—Milner Hurd Patent Side-flue Lever.

There being no direct method of a practical nature for direct localisation of leakages through the baffle walls, the only way to deal with these is to make a thorough examination and close all cracks or fissures, even where there may be only a suspicion of leakage, so as to leave nothing to chance.

Special attention should be given in B. & W. boilers to the space between the header boxes of the superheater, also at the points at which the blow-down and superheater drain-pipes pass through the external walls.

In Stirling and similar types of boilers considerable air leakage is apt to be encountered around the ends of the drums and in the vicinity of the superheater boxes on the boiler top; and internal leakage is often due to baffle bricks having bodily fallen out, leaving a hole about 1 ft. square through which the hot gases pass direct without passing through their complete circuit.

Economiser Brickwork

The principal points of leakage in economiser brickwork is at the junction of the flue tops and enclosing walls with the top boxes of the economiser sections.

The brickwork around the lower or inlet branches from the bottom boxes to the inlet headers is also a position in which leakage often takes place.

Class of Bricks Used

Ordinary stock bricks are as reliable as any for the external walls of boilers and economisers. Blue bricks should never be used, as they are certain to crack with the heat and will not stand any considerable variation of temperature.

White glazed bricks are often used for the outer facing of boiler walls owing to their absence of porosity and convenience in cleaning, as well as for appearance sake. Nevertheless the use of this type of brick is open to several objections. The bricks are usually soft, and have a considerable tendency to crack. When this takes place it is very difficult indeed to point them satisfactorily, and tarring is quite useless.

Cement should not be used for setting bricks that are to be exposed to wide variations of temperature, ordinary mortar being the most suitable in every respect.

Fire-brick linings should be of good fire-clay bricks. Silica bricks must not be used, as owing to their expansive properties they cause the linings to bulge inwards and collapse, or else set up strains and stresses in the metal of the boiler and other brickwork which has not been designed to withstand it.

For economiser and other flues where the temperatures do not exceed 500° F. the use of fire-bricks is quite unnecessary, but where this temperature may be exceeded a lining of fire-bricks is an advisable precaution.

On large water-tube boiler plants, where the gases enter the economiser at about 480° F. and leave often below 300° F., a lining of " Iron " bricks makes a very satisfactory job.

For the linings that are subject to very high temperatures such as the furnaces and other portions of the boiler near the fire, very high-grade fire-bricks should be used such as the " Glenboig " or " Castle Cary " brands.

The cost of maintenance of fire-brick linings for boilers would be greatly reduced if more attention is given to the fire-clay setting than is usually the case. Fire-clay is at present the only available cement, but its adhesive properties are very poor. To set fire-bricks correctly all that is required is to dip each brick in a fairly thin wash of fire-clay and rub the brick down to a joint. If thick joints of fire-clay are used, the bricks rapidly work loose and the whole job is likely to collapse in a very short space of time.

CHAPTER XVI

RADIATION OF HEAT.—Losses due to radiation and conduction—Non-conducting coverings; their importance and relative values—Coverings suitable for various temperatures and situations—Insulating fire-bricks—Bearing of design of pipework and accessories upon conduction losses—Care of coverings.

ACTUAL leakage of steam from steam pipes and elsewhere is usually dealt with as speedily as circumstances will permit owing to its immediately attracting attention.

The loss of heat from every pipe, boiler, etc., which is carrying steam or water at a higher temperature than the surrounding atmosphere does not receive the attention to which it is entitled by its very great importance, owing to this loss being invisible.

The term " radiation " as is generally applied to this loss of heat is quite incorrect, as radiation properly so-called plays no part in the process. The only place and time where and when true radiation losses take place from a boiler are at the furnace door, principally when this is opened for firing, etc.

When two bodies are placed in contact, one being at a different temperature to the other, the heat tends to travel from the hotter to the colder body till equilibrium is attained. This process is called conduction. The rate of heat transfer that takes place is dependent upon the heat conductivity of the two bodies, together with their difference in temperature.

The metals, especially copper, are particularly good conductors of heat, whereas at the other end of the scale we have air, water, and certain other substances which are very poor conductors of heat.

The conditions of heat dissipation from the surface of a hot steam pipe to the surrounding atmosphere are those with which we are most nearly concerned. Although air and water in themselves are very poor conductors of heat, the fact that under ordinary circumstances they are free to move and circulate (*i. e.* they are *fluid*) largely nullifies the property of non-conductivity. The layer of air actually in contact with the hot metallic surface loses in density or weight as its temperature increases, and therefore rises through the cooler and denser zones round about it.

The hot air which has left the pipe is replaced by cold air, and thus a continual upward motion is created. This circulation of air due to heating is called " convection." The term " radiator " used in connection with steam heating apparatus is therefore a misnomer, the name of "convector" being the proper term; and this is in fact used to describe electrical heating apparatus which is non-luminous, as true radiators electrically operated are also obtainable.

The loss per sq. ft. of hot surface per hour per degree F. difference of temperature is shown in the chart Fig. 117, for various steam pressures and temperatures also the loss in cwts. of coal per sq. ft. per annum with coal at 13,000 B.Th.U., 75 % boiler efficiency for a range of working pressures. A study of these charts should convince the most conservatively minded engineer of the great losses that may be incurred through inattention to the subject of heat insulating coverings.

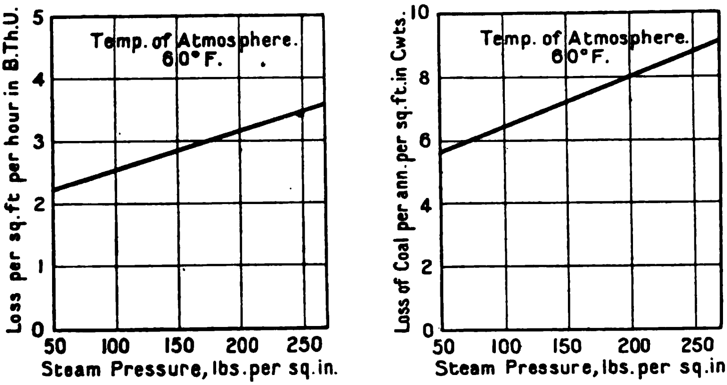


FIG. 117.—Charts showing Losses from Bare Pipes.

Non-conducting Coverings

All the most effective coverings for reducing heat losses are those which in their natural formation are of a microscopically porous or capilliary nature. As such they hold entrapped within their minute cells a large quantity of air which is prevented from convection by surface tension and friction.

Hair Felt is about the most efficient covering procurable owing to the tubular structure of hair, of which this substance is manufactured.

Slag Wool or Silica Cotton also owes its great effectiveness to a similar tubular formation of each thread.

Magnesia, another covering of high efficiency, forms minute self-contained cells on drying.

Fossil Meal, Infusorial Earth or Kieselguhr is a very good insulator which is composed entirely of microscopical shells of fossilised animalculæ which provide the receptacles for entrapped air.

Asbestos is very largely used for lagging purposes and is of a varying value, the non-conducting properties depending upon the length of the fibre of which it is composed.

The above-named materials are the only ones that should receive any consideration in connection with their non-conducting properties.

The hard-setting compositions still very widely used for lagging purposes should not be entertained, except as protective coatings for other and more efficient coverings. The difference in cost is usually wiped out in considerably less than a year by the decreased loss obtained with the higher priced coverings. In fact, the difference in price usually finishes with the cost per ton, as the common compositions as a rule have a very small covering power compared with such material as magnesia and, to a less degree, asbestos.

The covering power of three typical plastic compositions are as follows—

Composition.	Insulating Efficiency.	One Ton Covers, two inches thick.
Magnesia 85 % + Asbestos Fibre 15 %	92 %	1000 sq. ft.
Asbestos + Fossil Meal . . .	75 %	400 ,,
Common Cheap Composition .	40–55 %	200 ,,

The *efficiency* mentioned in the second column is the amount of heat retained in the pipe, etc., that would have been lost from a similar area of uncovered surface at a steam pressure of 150 lbs. per sq. in.

Hair Felt has already been mentioned as about the best heat insulator, but as it deteriorates under the influence of high temperatures, its use is limited in practice to the covering of cold pipework as a protection against frost. Even with moderate temperatures hair felt pulverises and becomes useless fairly rapidly.

Slag Wool or Silica Cotton should only be used for contact with metal if it is obtained from basic steel furnaces, the slag used in the acid process of steel melting having a highly corrosive effect upon ironwork when it becomes moist. Slag wool has an efficiency as a heat insulator of over 90 %, but as it cannot, at present, be applied satisfactorily in the plastic form, it has to be supported in position by some other means.

The patented method adopted by Messrs. Sutcliffe Bros. of Godley for covering steam pipes with slag wool is shown in Fig. 118, in which A is the steam pipe, B spiral spring fastened tightly around the pipe, E the slag wool insulation which is held in position by the sheet-steel casing C, the whole being secured tightly by the band D. The spring supports in this system ensure a maximum grip upon the pipe, together with as small an area as possible of metallic contact so as to avoid conduction of heat from the pipe to the outer steel covering.

Another greatly used and cheaper method of applying slag wool to pipework is the sectional system, the wool being encased in thin asbestos paper, the whole being made up in cylindrical lengths of about 3 ft. each on the pipe. This covering may be finished and protected either by sheet steel or by waterproof canvas, this being laced or otherwise tied on.

Attempts have been made to apply slag wool in the form of a plastic composition, but so far without very great success.

For covering such places as boiler and economiser tops, slag wool is sometimes used in the form of a mattress, the enclosing medium being woven asbestos cloth.

A boiler top partially covered by Messrs. Sutcliffe Bros.' method is seen in Fig. 119. In this case the use of springs is impracticable, and instead bridges of steel with inwardly projecting points are used to support the outer steel casing.

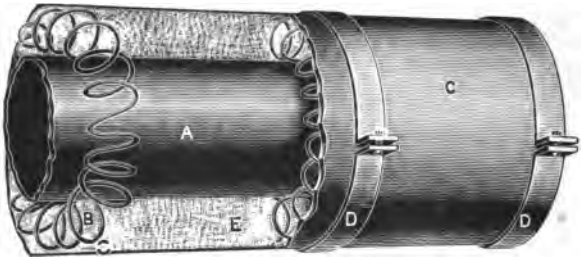


FIG. 118.—" Crown " Patent Slag-wool Pipe Covering.

Magnesia is applied either in a moist, plastic state to the hot metal, on which it is allowed to dry, or may be obtained in moulded blocks specially formed to fit the contour of the surface it is intended to cover. These blocks are usually covered with canvas and finally secured by metal bands.

Magnesia is of equal heat insulating value to that of slag wool, averaging somewhat over 90% efficiency.

Asbestos is considerably cheaper than magnesia, but is of lower efficiency, a good quality being about 75 %. It is applied in the plastic form.

Fossil Meal is rather poorer in cohesiveness, but is largely used as a finishing coating upon asbestos coverings to give a smooth surface for final varnishing. Its efficiency is about 75 %.

Woven asbestos rope wrapped around a steam pipe makes, probably, the most durable covering possible, if it is applied correctly. The proper method is to knock each turn down tightly with a mallet, as the covering is being put on. If this is done carefully, asbestos rope covering will withstand the most heavy vibration, such as that experienced with steam hammers and drop-stamps. The ends of the rope are secured to the body of the covering by means of copper wire, and the whole covering should be finished by a wrapping of strong canvas finally sized and varnished. To keep this covering from slipping on the pipe a " tundish " fitting or clip is fastened securely to the pipe as a support. A bend covered in this manner is seen in Fig. 120. A high efficiency covering is made of asbestos rope filled with magnesia. These rope laggings are expensive, but as even the most expensive class of non-conducting coating will repay its cost within the course of a year under the usual working conditions, the first cost is really of little importance.

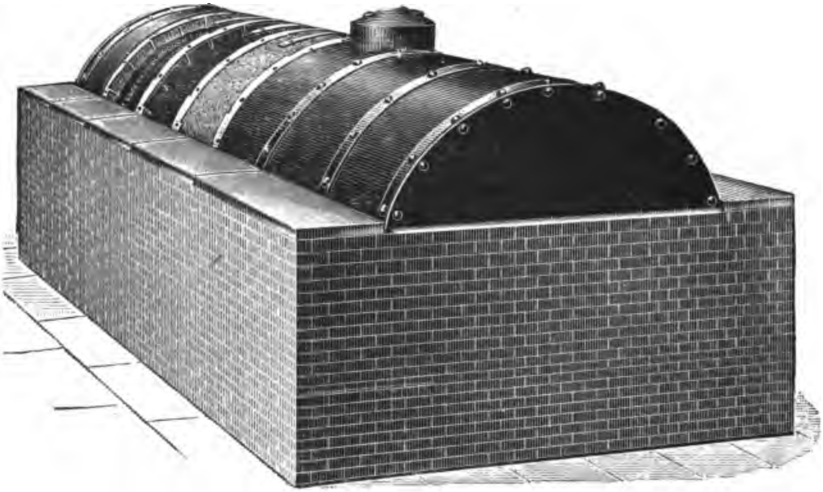


FIG. 119.—" Crown " Patent Slag-wool Boiler Covering.

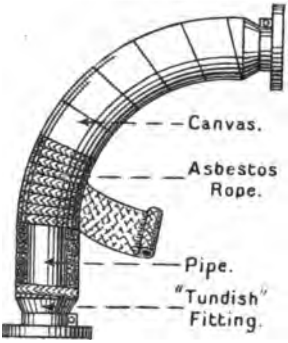


FIG. 120.—Asbestos Rope Pipe Covering.

The efficiency of a non-conducting covering is affected to a considerable extent by the finish of the outside surface. Experiments made by investigators in this subject have conclusively proved that a rough surface dissipates much more heat than a smooth one. Therefore it is important that all coverings should be finished off as smoothly as possible.

With heavy vibration, in addition to the rope lagging mentioned, the plastic laggings are quite suitable providing that they have sufficient reinforcement by means of sheet metal covering, held securely and tightly by means of steel bands.

Slag wool is not recommended for heavy vibration, as it is very apt to shake down and pulverise, when it becomes quite useless.

For such positions as locomotive and steam-crane boilers an effective covering is slag wool held in position by wooden laths and finished with a layer of common hard-setting composition. The whole, of course, is covered with the usual sheet-metal casing and bands.

For moderate degrees of vibration such as engine steam-pipes the plastic laggings should be reinforced with a layer of wire netting embedded in the composition and another layer of netting upon the outside of the covering before final varnishing.

With turbine power plants, heating apparatus mains, etc., where vibration is negligible or non-existent, plain plastic coverings without reinforcement are quite suitable.

A plastic lagging for general use and which will withstand all normal conditions may be made up with a first layer of common hard-setting composition about ½ in. thick upon which is applied 1 in. of magnesia and finished with another ½ in. layer of the common compo. Such a covering is suitable for any saturated steam temperature, but for superheated steam the common composition is quite unsuitable and rapidly deteriorates. Magnesia, slag wool and asbestos are the only practicable coverings for high temperatures.

The heat losses through the external brickwork of boiler flues, especially in connection with water-tube boilers, also from the walls of metallurgical furnaces, have had little or no attention in the past although they may reach a very considerable amount.

A fire-brick that will withstand moderate temperatures has been placed upon the market by Messrs. Newalls Insulation Co. of Newcastle-upon-Tyne. These "Nonpareil" bricks, as they are called, are manufactured largely of diatomaceous earth (fossil meal) to which is added a proportion of selected clay and finely graded cork granules. The insulating value is claimed by the makers to be ten times that of red bricks or ordinary fire-bricks. These bricks are stated to withstand a temperature of from 1600° to 1800° F. without disintegration, but are recommended to be used as an intermediate course built in between the ordinary fire-brick lining of flues, etc., and the outer face of red or other bricks. They should have a very wide field of utility in connection with outer walls of boilers, flues, furnaces, economisers, etc.

Several important points should always be borne in mind when considering the matter of non-conducting coverings.

The fact is that a vertical pipe or surface will dissipate heat much more rapidly than a horizontal one. Although this is so, yet it is the vertical pipes and surfaces such as vertical boilers, Lancashire Boiler fronts, etc., which are most neglected in the matter of protection from heat loss.

A little consideration will make it clear that the longer a vertical hot surface is, the greater the velocity of the upward convection currents. As the heat dispersal increases with the velocity, the importance of this matter will be apparent.

Another point is that, owing to the enormously increased ratio of external surface to the volume of contents in small pipes compared with larger ones, the heat loss from the small pipes is a great deal more in proportion.

The next matter to receive consideration is the heat loss from pipe joints. In ordinary steam mains the metallic surface of the joints will represent 10 % of the whole system with steel pipes and plain flanges, and fully 20 % if cast-iron pipes with ribbed flanges are used.

It follows from the above that no hot surface whatever should be left uncovered, and this applies especially to vertical pipes such as those to traps and drains, boiler fronts, vertical boilers, and also to steam and hot-water pipe joints, valve bodies, steam trap bodies, etc. Economiser tops also should not be neglected in this respect.

The very prevailing practice of covering boiler tops with bricks has little to recommend it beyond the mechanical strength. Bricks are of little insulating value (about 30 %), and the mortar used is very liable to set up corrosion of the metal surfaces when cold and damp.

The practice of judging the efficiency of a non-conducting covering by the degree of sensation of heat experienced in placing the hand upon it is quite unreliable, unless the finish of the surfaces to be compared are identical.

A rough surface that is dissipating heat rapidly will feel *cooler* than a smooth surface that retains the heat, the surface temperature being higher in the case of the more efficient covering than that of the poorer one.

In designing steam-pipe arrangements the question of heat loss should be carefully considered.

Expansion of pipes is usually provided for by means of U-shaped bends, and these offer a very large surface for dispersal of heat. Therefore this provision for expansion must not be excessive. Conduction losses through hangers and other pipe supports should be reduced as far as possible by the insertion of a layer of ¼ in. asbestos millboard between the stirrup of the hanger and the pipe itself.

Considerable loss may be avoided by placing steam traps as close as possible to the pipes that they are intended to drain so as to avoid the long vertical pipes that are usually found in connection with these appliances.

It is unfortunately the case that all good heat insulators are in themselves deficient in mechanical strength, and consequently liable to damage by rough usage.

Perhaps the position where lagging is most subject to damage is around boiler manholes and on boiler tops. A very efficient protection for plastic boiler covering is very small mesh wire netting, but this has a disadvantage in its tendency to accumulate dirt and dust which cannot be swept off.

" Rubberoid " sheet is another excellent protection of lagging from the effects of persons walking upon boiler tops.

The necessity for walking upon boiler tops should be avoided altogether by providing proper gangways across the boilers with platforms at valves, etc.

All coverings should be protected from condensed water from leaky joints or glands dripping on to them. If this is neglected the covering gets washed away and also become saturated so that its heat-insulating properties are destroyed. Corrosion of the boiler shell may also be set up by wet lagging.

The term " radiation " in connection with heat losses is probably responsible for the neglect usually observed in covering the steam mains for heating apparatus where these pipes are carried overhead.

As all the heat emitted from such overhead pipes passes directly upwards with the convection currents, it achieves no appreciable result in heating the buildings, and for all practical purposes is lost.

It is an accepted axiom with heating specialists that the object to keep in view is that " the feet should be warm and the head cool," this representing the requirements for comfort without oppressiveness.

Bearing this principle in mind, it follows that all pipework 5 ft. or more above the floor level should be effectively lagged, with much improved efficiency in the heating arrangements.

CHAPTER XVII

STEAM MAINS.—Sizes, arrangement, reliability, condensation, levels, supports—Valves, traps, and other accessory fittings.

THE sizes, arrangement and fittings in connection with a system of steam mains will have a very important bearing upon the economy and efficiency of the plant with which they are installed; and it is from the above point of view that the subject of steam mains will be discussed.

The size of steam pipe used for any particular purpose should be the smallest permissible with regard to drop of pressure through its length.

The use of pipes of larger diameter than necessary leads to increased heat losses and condensation owing to the larger area of the external pipe surface.

It is outside the scope of this work to give any rules, formulæ or tables of steam-pipe sizes, and apart from other special considerations which will govern each individual case, the point mentioned in the previous paragraph should always be kept carefully in mind when designing the proportions of a system of pipes or reconstructing an old one.

All pipes should lead as directly as circumstances allow from one point to another, and, beyond reasonable provision for expansion, bends should be avoided.

The "ring-system" of steam mains leads to a multiplicity of valves and undue amount of live steam piping with consequently heavy condensation losses. The pipe system and joints should be designed to be of utmost reliability in the first instance, so that the chances of failure may be made as remote as possible.

The necessity for shutting off, making "dead," and recharging mains is responsible for great losses of heat, and as this is frequently necessitated through failure of joints, the importance of sound work in this direction cannot be over-estimated.

Three types of flanged joints are shown in Fig. 121. A is a plain flange with machined faces, and though very widely used cannot be classed as the most reliable, especially with steel or bronze flanges. The flanges are apt to become hollowed owing to their being drawn down over the edge of the jointing ring if this is entirely within the bolt circle. For this type of joint the ring should cover the whole of the flange, the bolts passing through holes *cleanly* punched out of the joint ring.

The joint shown at B (Fig. 121) has the disadvantage that great strain is thrown upon the flanges by the tension of the bolts, but avoids the tendency to become hollow.

The most reliable joint, which cannot blow out, is the male and female pattern C (Fig. 121). One flange is formed with a recess $\frac{1}{8}$ in. deep in its face within the bolt ring, the other flange having a projection or boss about $\frac{1}{16}$ in. less in diameter than the recess in the opposite flange, the projection being $\frac{3}{16}$ in. thick. The author has known joints of this description to remain tight for over twelve years with high-pressure steam which has been sometimes very wet, and at others highly superheated.

Flanges on pipes of 6 in. bore upwards should be riveted, and caulked both sides. Where screwed-on flanges are used the pipes should be expanded into the flanges and both sides of the flanges caulked.

If screwed-on flanges once start leaking from the thread, it is very difficult always, and sometimes impossible, to repair them successfully to hold for any further length of time. This also applies to socket joints.

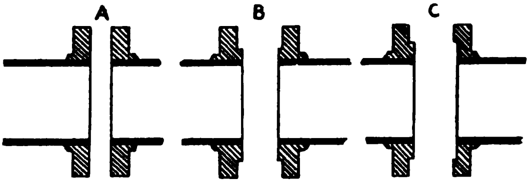


FIG. 121.—Flanged Pipe Joints.

The reliability of a steam or water pipe joint depends largely upon the class of packing used for making it.

One of the most reliable and widely used joints is Taylor's corrugated metallic ring. This is so well known as to need no particular description. For saturated steam the brass ring is quite suitable, but for superheated steam nickel steel or nickel rings should be used, while for water services the copper rings should be utilised.

The sheet jointings are quite suitable for low-pressure work, but even for this purpose the corrugated metal rings are to be preferred.

The levels of pipes should always be arranged to slope in the direction of the flow of the steam, that is, away from the boiler. By following this rule the drainage points are reduced to a minimum. The levels of steam pipes should be checked at regular intervals, as the probability is, that under varying conditions of temperature and pressure the pipes will not lie in the same position as when they are cold. To preserve the proper slope of the piping the supports should be adjusted whenever the fall is found to be incorrect. All supports should therefore be adjustable, and also allow free longitudinal movement of the piping during expansion and contraction.

All steam mains should be anchored or held rigidly at a suitable point so that the expansion and contraction is equally distributed in each direction. If this is not carefully attended to the greatest strains and stresses will be thrown upon the weaker branch pipes, owing to those of larger size offering greater resistance to deflection from their normal position.

The position for such anchorage in straight pipes is usually at the centre, while for other cases the position must be chosen with regard to the special circumstances obtaining in each case.

Sufficient valves should be provided to meet all requirements for sectioning the steam-pipe system so that no lengths of pipe remain charged with steam when not in use.

Whenever a new length of steam main is completed and ready for use it should be thoroughly blown through for two or three minutes with a full head of steam so as to clear all particles of jointing composition and material, metal borings, grit, scale and other matter from it which would otherwise choke up drain-pipes and score and damage the valves.

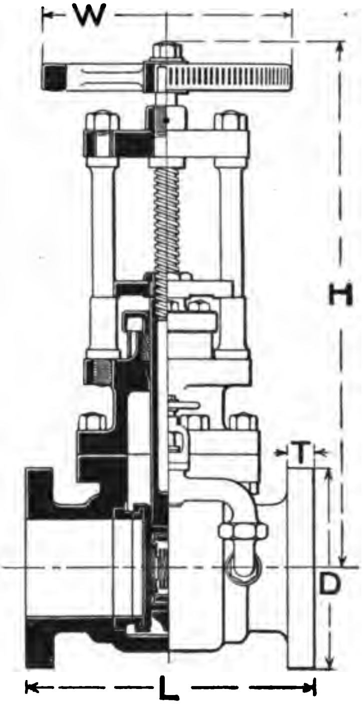


FIG. 122.—Hopkinson's Parallel Slide Valve.

VALVES

Valves for use on steam mains should always be of the full-way or sluice type. Globe or mushroom valves, besides offering considerable resistance to the flow of steam, have the disadvantage that they form water pockets unless they are fitted with the spindle in a horizontal position, and in addition they are not to be recommended for high pressures.

As a type of high-class full-way valve the Hopkinson make shown in Fig. 122 may be mentioned. Valves of this type do not depend upon any strain on the screw for tightness, this being obtained by the actual steam pressure upon one face of the valve holding the other face tightly upon its seating. If a sliding valve does become leaky it is useless to put tension on the screw by means of the wheel, which practice will only lead to damage of the valve by bending the bridge stop, and in doing so allow steam to pass above the valve.

In order to avoid the large size of valve usually needed for the larger bore pipes, the Hopkinson-Ferranti valve (Fig. 123) has been devised and very largely adopted during the last few years. It consists of a small slide valve fitted into the " throat " formed by the convergent portions of two nozzles. The design of this double nozzle is such that there is no loss of pressure of the steam after passing through the valve, although the valve itself is only about one-half the diameter of a " full-bore " valve for a pipe of the same size.

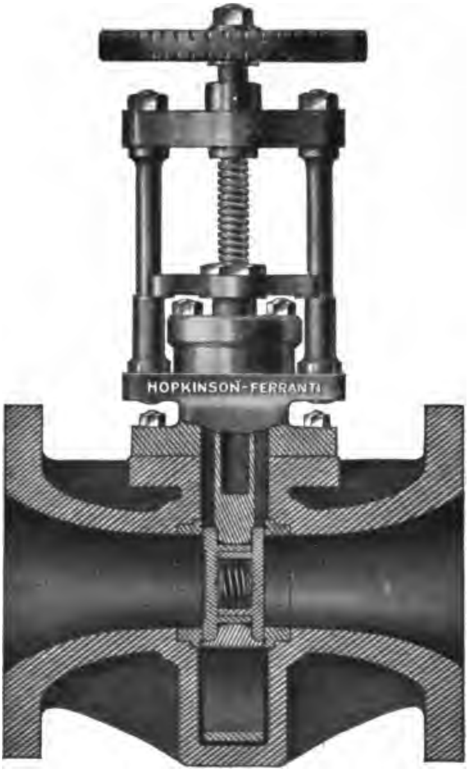


FIG. 123.—Hopkinson-Ferranti Valve.

Valves for high-pressure steam should have cast-steel bodies, while cast iron is suitable for pressures up to 100 lbs. per sq. in. For superheated steam bronze valves must not be used, but the valves and seats should be made of a special nickel-steel alloy specially manufactured for the purpose.

Small valves are very liable to leak if not of a well-made type, and it is always advisable to instal the best quality valves, large or small, as initial low price is usually more than counterbalanced by loss in steam wastage and also in repairs and maintenance.

It is preferable to use nickel steel valves and seatings for all pressures, as this policy will invariably pay for itself in the long run.

Valves, like all other mechanical devices, need proper attention and care so that they may be trusted to operate satisfactorily whenever required. Wherever possible every valve should be opened and closed at least once per week, the spindle, screw and guides being thoroughly cleaned and oiled at the same time.

The packing used for valve spindles should be of the best, and there is no doubt that a very large wastage of fuel takes place annually, through steam leakages from leaky valve glands.

For all types of valves the best form of packing is a single turn of any round packing of correct thickness to suit the stuffing box, followed by a filling of *soft* asbestos fibre which has been intimately incorporated with flake graphite. Sufficient room is left at the top of the stuffing box to admit a second round of ordinary packing on top of the asbestos fibre before fitting and tightening down the gland.

Reducing Valves

In large installations of steam plant it is always advisable to centralise the steam supply from a large battery of boilers rather than to have several independent units scattered about, each working at a different pressure.

As the different purposes for which steam is required in a large works may necessitate a variety of steam pressures, some means must be utilised to obtain the various pressures from one initial high pressure. Several types of reducing valves are available, prominent among these being " Foster's Class W," a section of the pattern used for ½ in. to 2 in. pipes being shown in Fig. 124. This valve is manufactured by W. H. Bailey & Co., Ltd., and is made in all sizes from ½ in. up to 24 in. bore. The larger sizes are of the same general design as that shown, but differ considerably in details according to the size.

This valve is controlled and operated by the movement of a diaphragm opposed to the action of springs whose tension is adjusted according to the delivery pressure to be maintained, and this pressure is entirely independent of the pressure in the supply pipes. The steam or other fluid enters the valve at A, and flowing in the direction indicated by the arrows, finally passes out at B. In its course it enters the diaphragm chamber D, through port E, and causes the diaphragm to rise and close the valve H, in opposition to the power of springs J. These springs, adjusted by nut K, tend to open valve H against the delivery pressure bearing on the diaphragm F—one balancing the other. An equilibrium between the two forces is thus instantly established. If from any cause the pressure on the delivery side increases, this pressure bearing on the diaphragm overcomes the resistance of the springs and tends to close the valve, drawing it towards its seats until the equilibrium is restored. On the other hand, if the delivery pressure falls, the springs overcome the pressure bearing on the diaphragm and force the valve open until the equilibrium is again established.

The delivery pressure is regulated by adjusting the tension of the springs. Increasing this tension increases the delivery pressure.

Under reasonably fair conditions, and with a valve of the proper size, properly installed and adjusted to requirements, it is possible to maintain an absolutely uniform lower delivery pressure regardless of any variation of initial pressure.

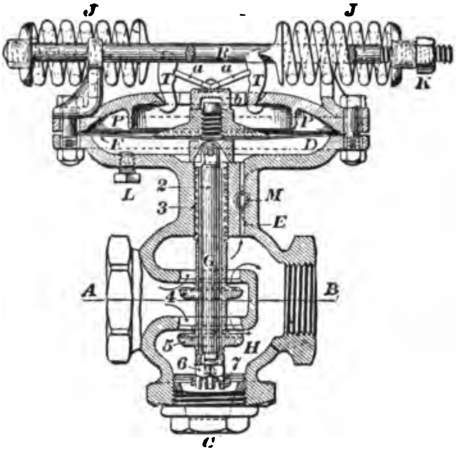


Fig. 124.—" Foster's Class W " Pressure-reducing Valve.

Pipe systems taking a supply of steam at reduced pressure from a higher pressure main should always have a relief valve and steam gauge attached so that any undue rise may be readily detected, and also as an indication of the adjustment and satisfactory operation of the reducing valve.

The supply of steam through a reducing valve causes superheat owing to the wire-drawing action, this being advantageous in that it ensures the absence of moisture in the low-pressure service.

Overflow or Surplus Valves

These are often misnamed " reducing valves." They are merely safety valves introduced into a high-pressure steam main, and which are arranged to blow off into an adjacent low-pressure steam main instead of wasting the surplus steam into the atmosphere.

Where there is a large demand both for high and for low pressure steam, it is an economical arrangement to instal sufficient high-pressure boiler capacity, allowing a margin above the largest possible requirements and limiting the low-pressure capacity as much as is permissible, so that any extra steam beyond that required in the high-pressure system is released into the low-pressure mains.

The advantage of generation of steam at high pressure has already been explained earlier in this book.

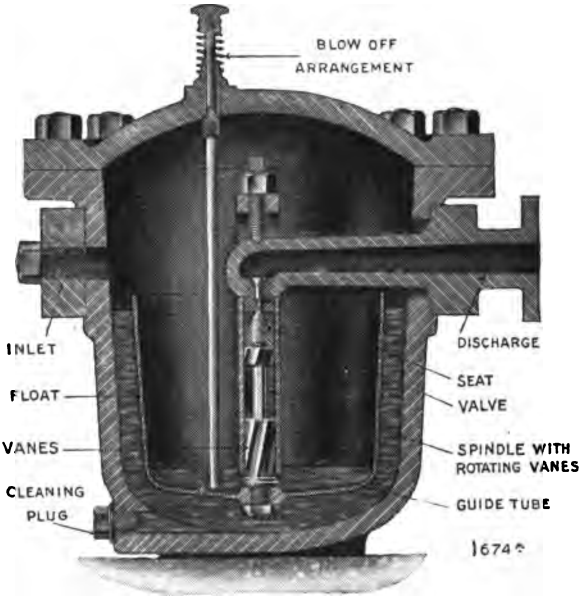


FIG. 125.—" Sentinel " Steam Trap.

STEAM TRAPS

It is impossible to exercise too much care in the selection of a suitable steam trap, of which there are several excellent and reliable makes upon the market, as well as a large number that do not answer to this description.

Steam traps may be generally classified in two groups, viz.: Thermostatic and Float types. As a class the latter are to be preferred to the former, as the thermostatic traps are very likely to be unreliable where the pressure and therefore the temperature of the steam is variable. That is to say, these traps, which depend upon reduced temperature to cause them to discharge, are liable to pass considerable amounts of steam when the pressure is low.

All the cheap traps of small size are of the thermostatic type, and as a general rule are far from reliable.

Three traps of the second or float class will be described as representing types of a good design.

The "Sentinel" Steam Trap of Messrs. Alley and MacLellan is shown in section in Fig. 125, and its action is as follows: The chest fills with condensed water which overflows into the float, filling it up and sinking it. In sinking, the float opens the valve through which the water is discharged by the steam pressure, and thus lightened, the float rises, again closing the outlet. Spiral vanes are formed on the spindle, and the water flowing up the tube impinges on these vanes, causing the float to rotate. This rotary motion attains its maximum speed as the valve is about to shut, and by the flywheel action of the rim of the float the valve is reground each time the trap operates. It will thus be seen that the life of the valve and seat is very much prolonged as compared with those in other types of traps.

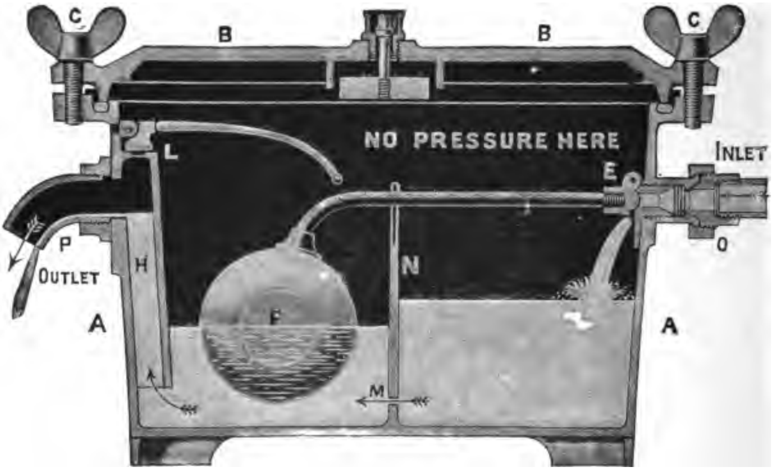


FIG. 126.—"Syphonia" Steam Trap.

Messrs. Royle's "Syphonia" trap operates upon a different principle. A sectional illustration is given in Fig. 126. The water of condensation flows freely out through the open valve E, following the course of the arrows up the syphon H into the atmosphere. As soon, however, as steam arrives and pressure tends to accumulate in the trap, the water is forced up the syphon pipe H, and the ball F, following the water down, partially closes the valve E. This ejectment action ceases as soon as the ball has so far closed the valve E that the amount of steam passing is absorbed by the natural condensation in the box. This valve E, therefore, never absolutely closes, and any condensed water collecting above the valve E at first slowly passes the valve, adds to the water in the box and raises the ball, thus lifting the valve E and discharging the water at a rapidly increasing ratio until the steam again arrives, when the water is driven out by the ejection pipe H and the valve E is closed as before. There is never more than a slight pressure in the trap, and the float F is therefore not liable to collapse owing to pressure.

The "Bradford" Steam Trap of the United States Metallic Packing Co. is another float-operated trap. A copper ball-float is arranged, by means of an ingenious and simple contrivance of levers and catches, to open fully and instantaneously the discharge valve when the containing chamber becomes full of condensed water. As the ball-float falls to the bottom of the chamber the discharge valve is released and closes instantaneously. There is an entire absence of wire-drawing and scoring of valves in this trap, as the valve is always either tightly closed or else full open.

NOTES ON TRAPS AND DRAINS

Traps should never be relied upon to drain steam ranges when these are being charged. A by-pass pipe and valve should be connected with each trap so that any water can be blown out through a full-bore pipe, the open end of which is visible.

Every trap and drain should discharge into a hot-well, so that the condensed water is available for re-use in the boilers.

Each trap should have a three-way cock fitted on the outlet, with an open-ended branch, so that ready observation may be obtained of the manner in which the trap is working. The arrangement by which the trap is made to discharge into a tundish is not to be recommended, as it usually results in water being thrown out all around whenever the trap operates in its correct manner.

STEAM SEPARATORS

These consist of a large "pocket" in the run of the steam pipe, provided for the purpose of drying the steam by removal of the particles of moisture suspended in it. The pocket is provided with some arrangement of baffles upon which the moisture and steam impinges, and this arrangement combined with the reduced velocity allows the water to accumulate in the bottom of the separator, whence it is discharged by a trap.

EXPANSION GLANDS

A telescopic length of pipe with stuffing box and gland is often used in long straight runs of steam piping to take up the longitudinal expansion and contraction. These should be avoided wherever it is possible by designing the pipework sufficiently flexible in the first instance, or by substituting U or "horse-shoe" bends wherever possible. Glands are nearly always more or less leaking, and in addition cannot be lagged to prevent heat loss; as a consequence they are a very wasteful device.

CHAPTER XVIII

EXAMINATION OF BOILER PLANT FOR DEFECTS AND LOSSES—Suggested system of procedure—How to improve conditions and effect economies.

IN order to carry out a thorough examination of a boiler plant with a view to increased efficiency and added economy a thoroughly methodical programme of procedure should be mapped out beforehand.

By following the directions to be given in this chapter the whole ground should be completely covered, and little (if any) source of loss or of possible economy escape observation.

The order of the various stages of examination should be as follows—

1. Methods and conditions of firing.
2. Size and suitability of coal used.
3. Construction of furnace.
4. Available draught and means of control.
5. Cleanliness of boilers.
6. State of brickwork.
7. State of valves and accessory fittings.
8. State of non-conducting coverings.
9. Housing of plant.
10. Working efficiency of the plant.
11. State of economisers, feed pumps and other feed-water apparatus.
12. Type and capabilities of firemen, etc.
13. Pay, hours, etc., of firemen.
14. Systematic keeping of running records.

The above points will now be briefly and concisely enlarged upon, with the appropriate remedies for any defects observed, all of which are treated at length in the particular section of this work specially devoted to their consideration.

1. *Method and Conditions of Firing*

Give careful attention to the method of firing; where spreading methods are used, perhaps side-firing or even coking methods may be substituted. Fire-bars should be kept clean by use of the slice-bar, so that the grate is never black when viewed from beneath.

Grates must be well covered throughout with incandescent fuel.

Firing should be done reasonably often and not with excessive quantities of coal at a time.

Look to the firemen's shovels; sometimes shovels of too large a size lead to over-heavy firing.

With chain-grate stokers the mixing of coal in the hopper should receive attention. Baffling of the coal chutes may often assist in keeping the coal well mixed.

See to the adjustment of sprinkler stokers so that the throw is correct.

With Underfeed stokers the distribution to each side should have careful attention. Experiment with different relative arrangements of fixed and moving bars.

In all types of mechanical stokers check any tendency for the coal to travel beyond the fire-grate unconsumed.

Examine the ash heap for excess combustible, test it for percentage ash in the laboratory, and see that grates are cleaned in a proper manner, that is to say, no unconsumed coke is being withdrawn or dumped with the ashes.

2. *Size and Suitability of Coal Used*

For hand firing see that the coal, if delivered in large sizes, is broken down to small cobble size.

Wherever possible order the coal of correct size, screened at the colliery.

Avoid the use of slack coals with hand fires. Select a free-burning coal of a fairly short-flame variety by preference for boiler work generally. Use long-flame coals for furnaces.

With mechanical stoking see that the coal which suits the conditions best is retained. Underfeed stokers particularly require careful attention in the selection of the coal to be used.

Test all coal for calorific value, moisture, volatile matter, fixed carbon and ash at regular intervals, so that the quality is constantly checked.

Test coal for evaporative capacity in the boiler whenever laboratory analysis indicates a variation.

Take up cases of deterioration of quality with the coal contractor or colliery.

3. *Construction of Furnaces*

See that the design of fire-bars is satisfactory as regards air admission capacity.

Examine fire-bridges for correct height.

See that there is ample provision for secondary air supply through the firing doors or over the furnace.

Build a refractory (fire-brick) arch over the front 3 ft. of fire-grate.

Provide openings with hinged cover at the bottoms of fire-doors for slicing purposes.

See that fire-grates slope sufficiently for ample combustion space and are not too long.

With chain-grate stokers see that the "coking arch" is sufficiently long.

4. *Available Draught and Means of Control*

Test the draught at the furnace, dampers, and at the base of the stack. These should be 0·25 in., 0·50 in. and 1·0 in. respectively for Lancashire boilers.

For water-tube boilers 0·4 in. should be available in the "middle chamber" and 0·25 in. over the fires.

Where shortage of draught is small a reduction of fire-grate area will probably suffice to raise the draught pressure to its correct amount.

Where "natural" draught is used and shortage is due to insufficient chimney capacity, an induced draught fan will be required to remedy matters.

Apply "chain seals" to economisers to minimise air leakage at chain holes.

See that damper slots are sealed with angle irons or other efficient means.

Introduce means of damper regulation from firing floor.

Have fan speed regulator conveniently to hand in stokehold:

Test temperature of gases at chimney base to ascertain whether excessive temperature is being used to maintain draught. Temperature without economisers should not exceed 650° F., and with economisers 450° F. for Lancashire, etc., boilers, and about 100° F. less in each case with water-tube boilers.

5. *Cleanliness of Boilers*

Keep a careful record of hours the boilers work between interna cleanings.

Examine boilers internally at intervals and ascertain the thickness of scale.

Determine the periods between internal cleanings by the number of hours run necessary to form $\frac{1}{16}$ in. scale upon the principal heating surfaces. This will vary in different situations according to the nature of the impurities in the feed water used.

Instal an air compressor and use pneumatic cleaning tools for rapidly cleaning the boilers.

See that the external surfaces of boilers are wire brushed and perfectly clean before setting to work again.

Clean the boiler flues wherever possible once per week or per 100 hours run.

Instal a vacuum dust-cleaning plant so as to avoid cooling-off losses both for boilers and economisers.

Blow the dust off the tubes of water-tube boilers, and brush multitubular boilers daily.

6. *State of Brickwork, etc.*

Make complete tests in various parts of gas circuit of boilers and plot combined chart noting the irregularities and deviation from normal.

Examine all external brickwork for air leakage and make tight wherever required.

Cover all external walls with tar in three successive coats.

Examine state of seatings and downtake walls, and make all defective portions sound.

Examine baffle walls and close all possible means of short-circuiting.

Caulk headers, and close spaces between connecting nipples of B. &. W. boilers.

Close all air leakage around ends of drums of Stirling and similar types of boilers.

Attend to the air tightness of places where superheater drains and flood pipes pass through walls.

7. *State of Valves, Joints and Accessories*

Examine blow-down valves for leakage.

Take careful measurement of the water in each boiler at intervals when at rest and note any variation in the level after two or three hours. With constant pressure no variation should be observed. This test will show whether any leakage is taking place, and should be carried out with the boiler under banked fires and not much below working pressure. Feel the blow-down pipe on the outlet side of the valve; if this is hot, leakage is taking place here.

Keep all glands of valves, etc., tight and use good quality packing—it will pay for itself in a very short time.

Examine all traps and drains for leakage.

Provide the traps with three-way cocks on the outlet with an atmospheric test branch, and make a regular routine of examination of traps.

Keep the valves and seats of safety valves ground in properly.

Carefully adjust H. & L. water valves.

See that safety valves are not underloaded.

Check the accuracy of steam-pressure gauges.

Replace expansion glands on steam mains by bends wherever possible.

8. *State of Non-conducting Coverings*

See that boiler fronts are efficiently covered.

Cover all manhole lids, steam-pipe joints, etc., against heat loss.

Examine nature and condition of covering already in use.

Abolish all common compositions and substitute high-efficiency lagging.

See that covering is of sufficient thickness.

Protect the covering of lower portion of boiler fronts with sheet-steel fenders.

Line outer walls of boilers, flues and economisers with insulating fire-bricks.

Remove brick coverings of boiler shell crowns wherever in existence and replace with more efficient lagging.

See that plastic lagging is not being saturated and spoiled by water dripping from leaky glands and joints. Divert any such leakage by sheet-iron troughs or pieces of pipe until the leakage is made good.

Protect lagging with sheet metal where liable to damage.

9. *Housing of Plant*

Examine boiler-house for cold draughts and close up all unnecessary openings which allow wind to blow around the boiler tops and elsewhere.

See that plenty of room is provided for comfort of the firemen in firing, raking and slicing.

Provide ample lighting in front of and over the boilers, so that gauges are plainly visible and access to valves is made as easy as possible.

See that firing floor is not too low for the easy and convenient handling of the fires.

10. *Working Efficiency of Plant*

Carry out regular tests of the plant for efficiency, so that any deterioration may be observed and the cause looked for without delay.

These tests should be carefully explained to the firemen and their objects made clear.

Instal economisers wherever not at present used.

Make a thorough investigation for all hot and distilled water going to waste, collect this and utilise for boiler feed after necessary purification from oil and other objectionable matter.

Make a similar investigation with regard to exhaust steam with a view to its utilisation for feed-water heating.

Make use of exhaust steam for heating of buildings, driving low-pressure turbines, manufacturing processes, etc., wherever it is possible to displace " live " steam already in use.

Instal superheaters to reduce condensation losses and improve boiler efficiency. Use the highest degree of superheat that the plant will permit.

11. *State of Feed Pumps and Feed Heating Apparatus*

Indicate the feed pumps to ascertain steam consumption, state of piston rings, valve settings, etc., and correct any wastage.

Examine plungers and rings for tightness in the barrels.

Examine water valves and grind on to seats.

Carry out the above as routine work at regular intervals of time.

Instal ammeters with electrically driven pumps, and make tests of speed at regular intervals.

Keep record of current taken and pump speeds.

Overhaul the pump when above show an increase without sufficiently good reasons being apparent.

Examine a few pipes in various portions of the economiser at frequent intervals. Clean thoroughly whenever scale is $\frac{1}{16}$ in. thick.

See that the scrapers of economisers are working correctly and making their full travel. When this is not the case take immediate steps to locate the cause, such as dampness, oily chain wheels, correct reversing, etc.

See that inlet temperature does not exceed 110° F. or fall below 100° F. Use recording thermometers as a check.

Protect all hot-water tanks against heat losses and accumulation of dust, by means of wooden covers.

Keep tubes or trays of feed-water heaters cleaned of scale.

Clean and renew all filters at regular and sufficient intervals.

Abolish injectors for boiler feed when using economisers and use pumps instead.

See that injectors are correctly regulated by the firemen so that there is no overflow when working.

12. *Type and Capabilities of Firemen*

Study the characteristics of the firemen and try to maintain their interest in their work.

Impress upon the men the fact that their own and their employer's interests are identical.

Do not retain that type of man who needs bullying to make him work properly—he won't when your back is turned.

Select only thoroughly intelligent men who take a live interest in their work.

The old theory that "any man who can throw coal on to a fire is good enough for a stoker," is a most expensive one to adopt.

The men who keep their fittings clean and the boiler-house tidy are usually those who take the greatest interest and pride in their work.

13. *Pay, Hours and Accommodation of Boiler-House Staff*

Boiler firing must be treated as a skilled trade, and payment arranged accordingly.

Instal recording apparatus and institute a premium bonus scheme based upon the *efficiency* obtained.

Long hours are not conductive to efficient work, eight-hour shifts are the longest it is reasonable to expect a man to work and maintain an interest in it. Longer hours become drudgery.

See that the men are provided with means for washing themselves properly before going off duty, provide them with decent and clean accommodation for taking their meals and other purposes.

The remarks as regards hours and accommodation also apply to boiler scalers.

14. *Systematic Keeping of Running Records*

Keep regular hourly records either on a log sheet or by means of automatic apparatus of all the data necessary to ascertain the efficiency, condition of plant, and methods of operation at all times.

Data in connection with the coal consumption, feed-water quantity and temperature, steam pressure, CO_2 in waste gases, flue temperatures, etc., should be carefully recorded and kept in the form of charts.

Investigate any irregularities in these and correct at the first opportunity.

CHAPTER XIX

Coal and Ash Handling Plant.—Storage of coal—Deterioration of coal in stock.

Although the question of the handling of coal and removal of ashes has no appreciable bearing upon the efficient performance of the boiler plant proper, yet the working costs of the plant as a whole will be considerably affected thereby.

Except in the very smallest of plants, the cost of apparatus for the mechanical handling of coal and ashes will be amply repaid in a short space of time.

With hand-fired boiler plants using large-sized coal the field for mechanical handling is somewhat limited, but with machine stoking and small coal the conveyor and elevator find a very wide scope.

As already mentioned in another chapter, coal for hand firing should not exceed 4 ins. to 6 ins. " cobble " size, and most conveyors and elevators will deal quite satisfactorily with this class of fuel.

The question of handling of coal and ashes resolves itself into separate consideration of the following stages of operation, viz. :—

1. The unloading of the coal wagons.
2. Transport to bunkers or other storage.
3. Transfer or feeding into stoker hoppers.
4. Removal of ashes.
5. Storage of ashes and final disposal.

1. *Unloading of Coal Wagons*

Most modern railway coal wagons are provided with a door at one end for unloading purposes. To utilise this door to its best advantage requires the installation of suitable end-tipping apparatus. This may be accomplished either electrically, by hydraulic rams or by steam. The first or second methods are to be preferred as being more economical than steam drive.

The simplest form of end-tipping gear is an electrically driven winch situated over the rail siding at the correct distance from the coal-receiving hopper. The end of the steel rope of the winch is provided with a stirrup which is hooked on to the truck axle furthest from the end door, which latter should overhang the hopper before lifting. The end door is released and the truck

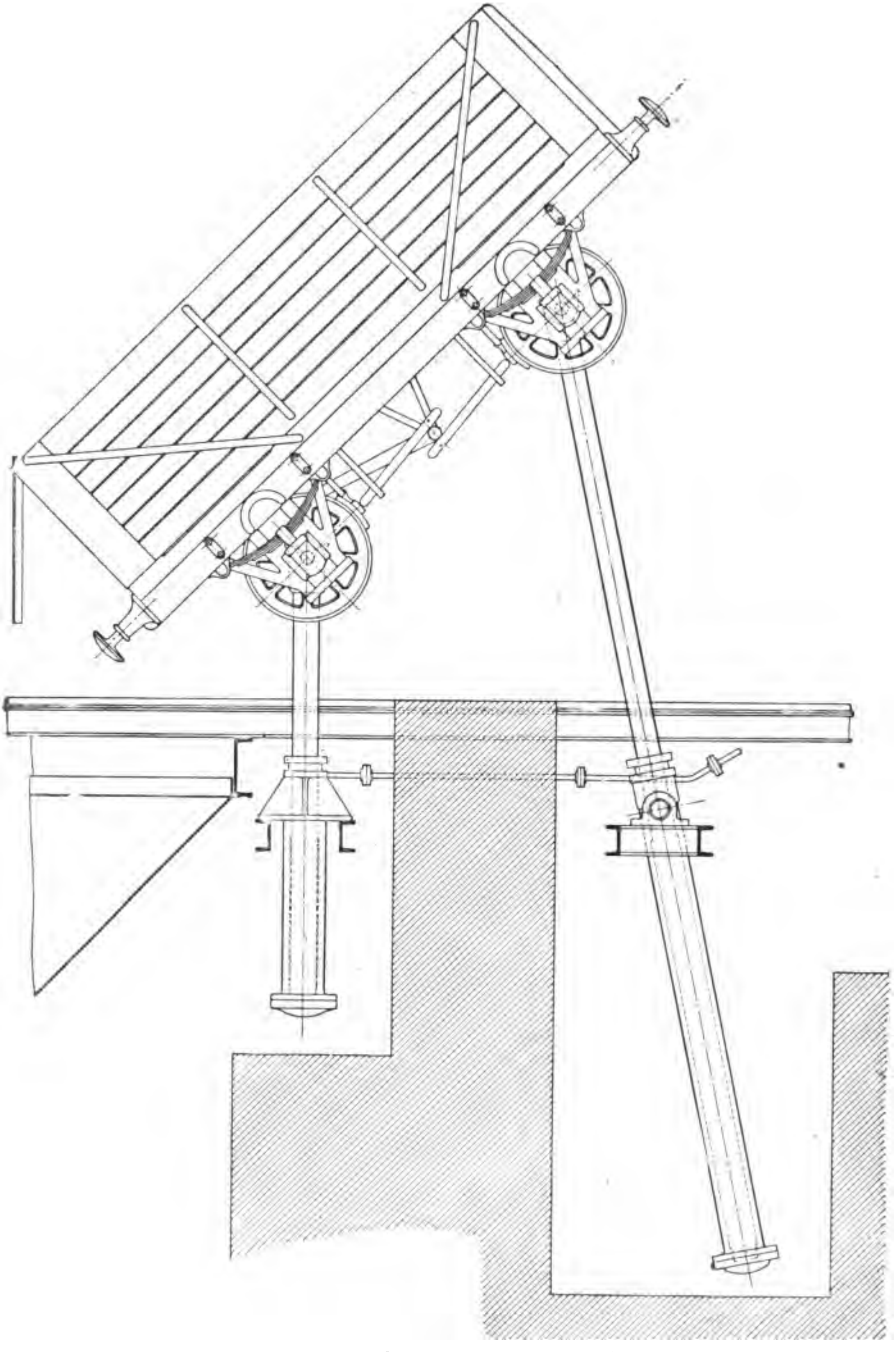


FIG. 127.—Babcock & Willcox Double-ram Tippler.

tipped up by the winch, by which at least the larger portion of the contents are discharged into the hopper. With nuts and other non-coherent classes of coal this type of tipping gear is quite sufficient. The lift being limited by the point at which the buffers of the wagon come in contact with the rail, the amount of tip allowed will not cause slack coals (especially when these are at all damp) to clear themselves from the wagon without assistance by hand.

To meet this difficulty with coherent coals, the double ram system (Fig. 127) may be used which allows a greatly increased angle of tip.

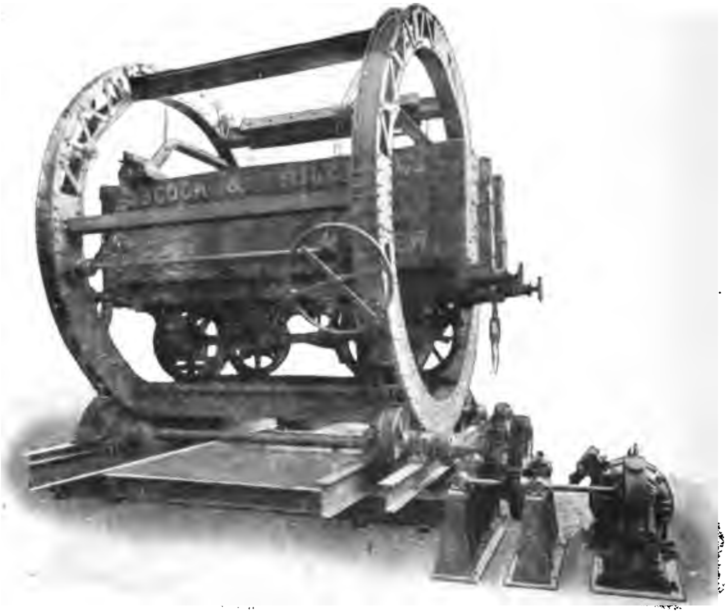


FIG. 128.—**Babcock & Willcox Rotary Tippler.**

The most effective and rapid method of unloading any class of coal is illustrated in Figs. 128 and 129, which clearly show the method of operation of a Rotary Tippler. The full wagon is run into the revolving cage and fastened down to the rails by crossbars and shackles. The whole cage containing the wagon is then turned through a complete revolution by means of an electric motor drive.

Even with damp, clinging coals every particle is emptied from the wagon into the hopper over which it is mounted, the slight vibration inseparable from the operation being sufficient to dislodge any adhesive masses of coal.

2. *Transport of Coal to Bunkers*

There are several mechanical means available for achieving this object, which may be divided into two classes, viz.: Continuous Conveyors and Automatic Railways.

Continuous Conveyors may be of the gravity bucket, open chain, tray or worm types, and in this class may be included the bucket elevators. All these conveyors are equally applicable for the removal of ashes.

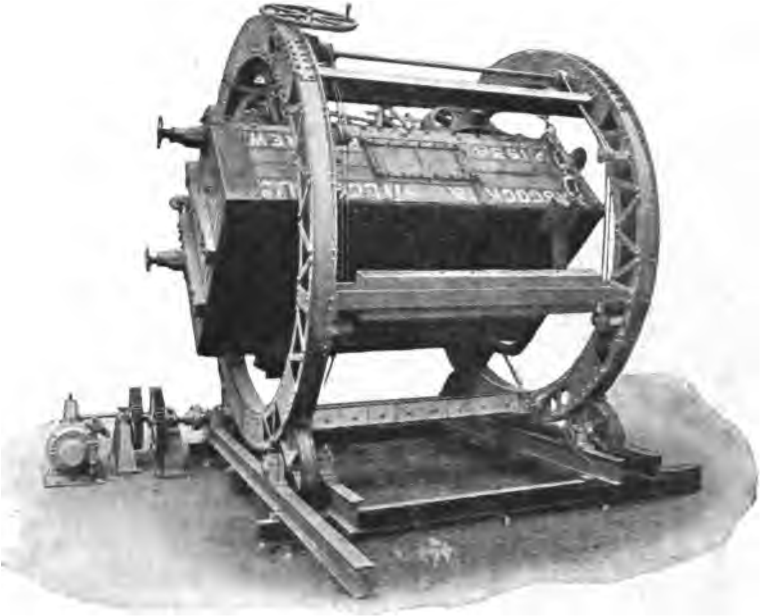


FIG. 129.—Babcock & Willcox Rotary Tippler.

Fig. 130 shows a gravity bucket conveyor by Messrs. Ed. Bennis, with a carrying capacity of 40 tons per hour.

The buckets swing freely between the two sides of the open chain, which is carried upon a pair of rails by means of small flanged rollers.

The buckets are tipped by levers fastened to the rail supports wherever required, the levers being provided with tipping arms which engage with projections on each side of the buckets. After passing the tipping levers the buckets fall back into their normal position by gravity. A specially arranged filling gear and automatically operated valve are situated below the hopper, into which the wagons of coal are discharged and beneath which the conveyor passes after the buckets are emptied.

Tray conveyors are somewhat similar in design to the gravity bucket type, and are made either to discharge over-end only or to be tipped at any desired point in their journey. Tray conveyors will not lift coal or other material vertically, but only up to a certain angle of inclination, which varies with the construction of the trays. Gravity bucket conveyors, on the other hand, are not limited in any manner as regards angle of elevation.

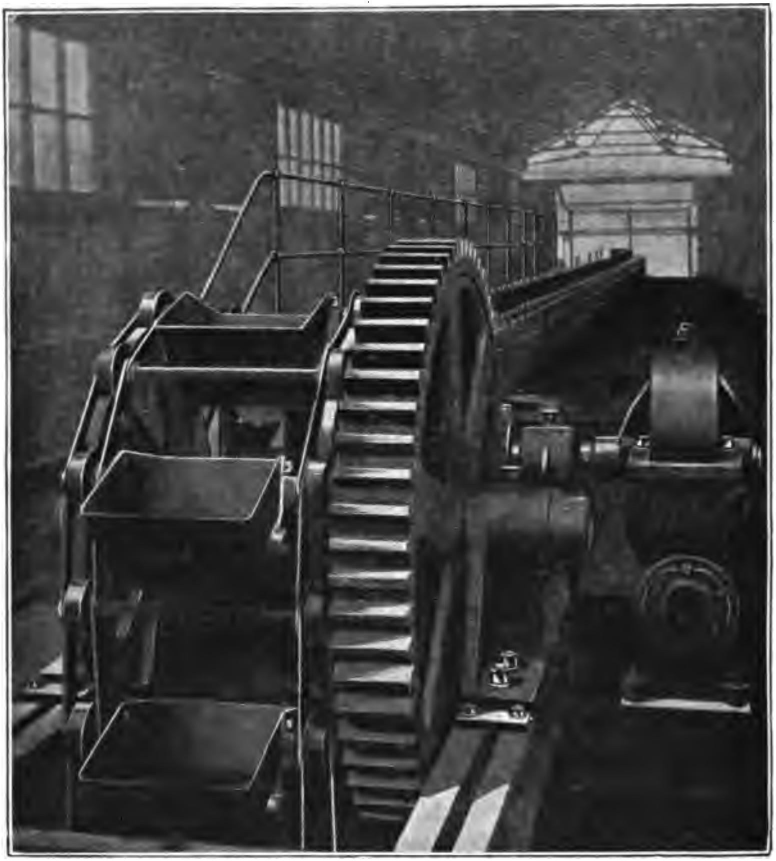


FIG. 130.—Bennis Gravity Bucket Conveyor.

Open chain conveyors consist of continuous cast-iron troughs along the bottom of which an endless chain is made to travel, each link of the chain forming three sides of a rectangle. Two of these conveyors are seen in Fig. 131. In this case also the angle of inclination is limited.

A great advantage of these chain conveyors is that no complicated filling gear is needed, the coal merely feeding by its own weight on to the chain. Where space does not allow of a long incline for raising coal from a hopper into overhead bunkers, a vertical bucket elevator is utilised which discharges into the chain conveyor, which only passes over the bunkers themselves. In this case the coal is unloaded from the wagons direct into the hopper and " boot " of the elevator.

Worm Conveyors (one section of such a machine being illustrated in Fig. 132).—The utility of this class of conveyor is somewhat limited, and is mainly installed in small plants to carry coal along and above the fronts of boilers for feeding stoker hoppers from one elevator or bunker situated at the end of the boiler-house. Chutes are connected to the bottom of the worm trough over each stoker hopper.

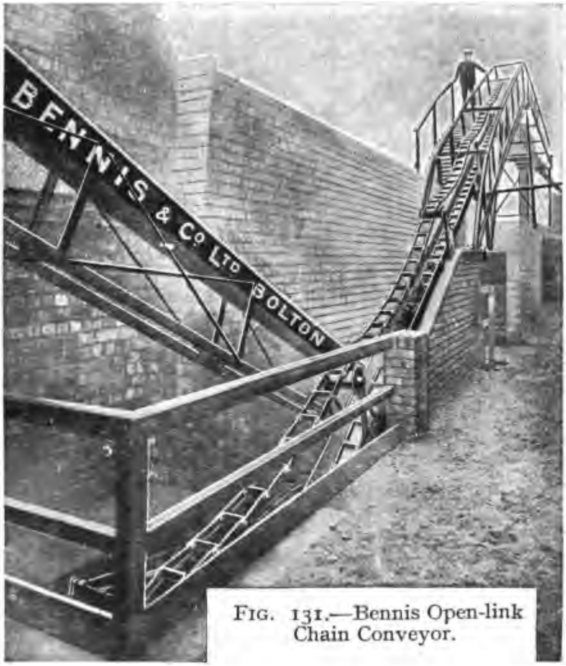


FIG. 131.—Bennis Open-link Chain Conveyor.

Conveyors in a boiler-house usually cause a heavy deposit of coal dust round about, and for this reason they should be kept outside wherever possible.

Bucket and tray conveyors have an advantage over the chain and worm types in that they do not tend to break up the coal as do the latter.

All receiving hoppers should be provided with gridiron covers, which retain any large lumps of coal that would otherwise jam in coal valves or otherwise interfere with the operation of conveying plant or mechanical stokers.

Other mechanical means of handling coal are by means of aerial ropeways and telpherage systems, and by means of automatic railways.

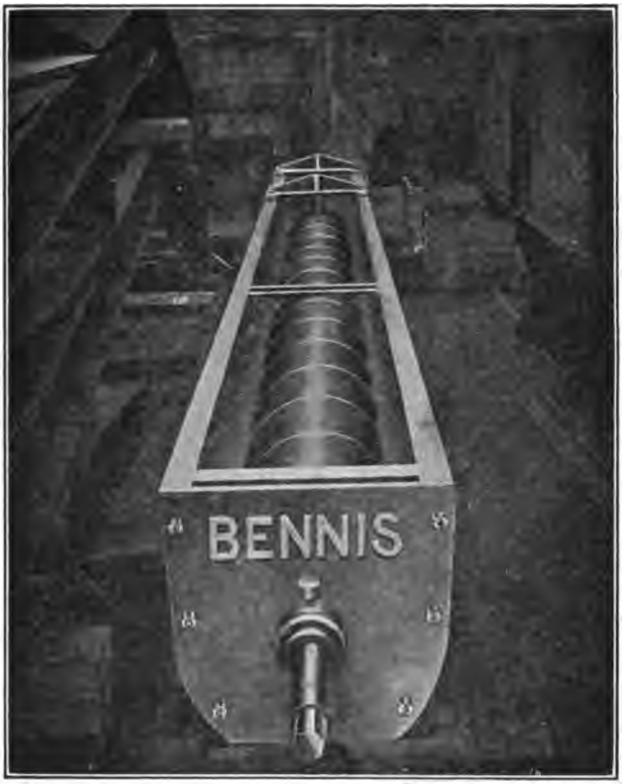


FIG. 132.—Bennis Worm Conveyor.

Aerial ropeway and telpherage systems are mainly useful for carriage of coal and ashes where a straight run in one vertical plane cannot be obtained, and this is specially the case when the distance to be traversed is great and where there are several turns in the horizontal plane.

The Automatic Railway is a most economical method of transferring coal and ashes from a high point to a lower level, the gradient of the railway being arranged so that the energy developed by a loaded truck passing down an incline is sufficient

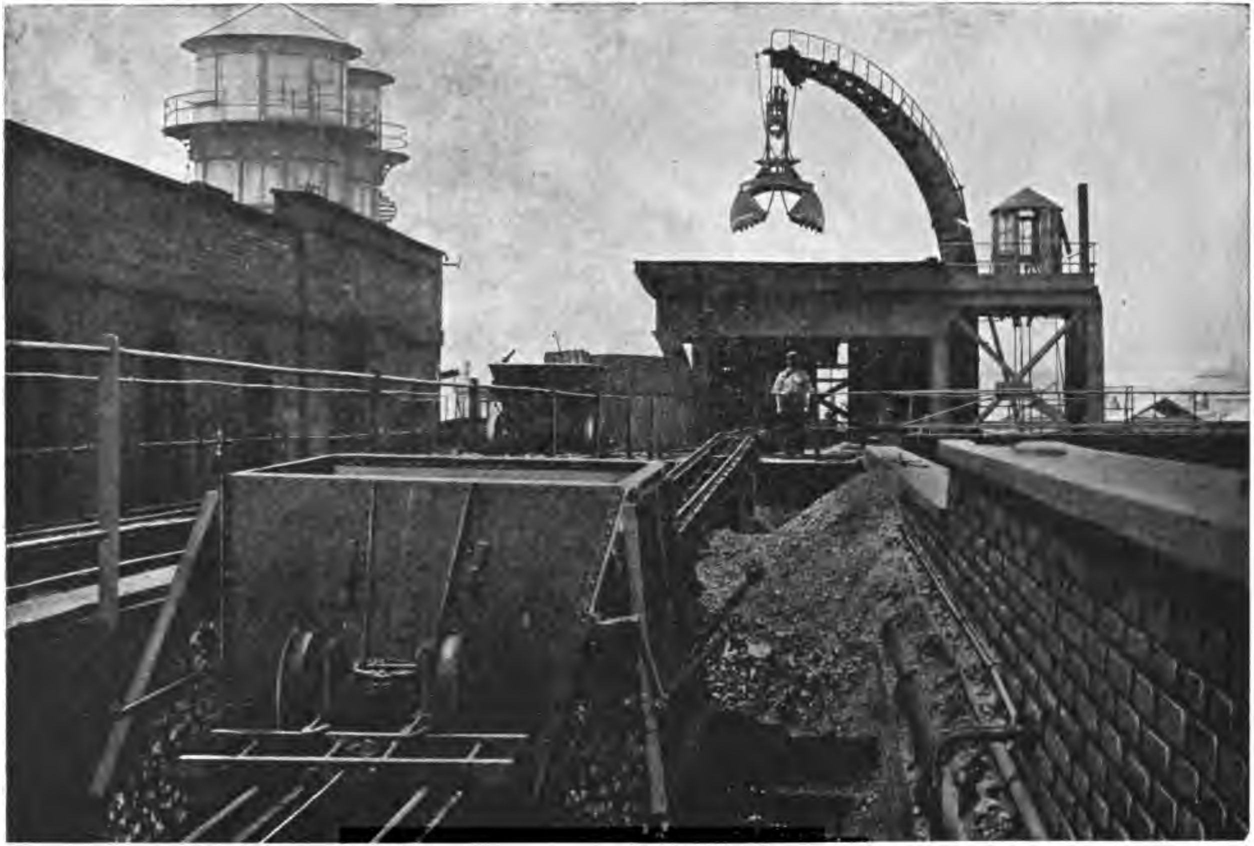


FIG. 133.—Babcock & Willcox Automatic Railway.

to return the truck—after it has discharged its contents—to the starting-point.

An example of such an installation by Messrs. Babcock and Willcox is seen in Fig. 133.

3. *Transfer of Coal into Stoker Hoppers*

Where overhead bunkers are in use the coal is fed directly by gravity into the stoker hoppers by means of chutes, which are provided with valves in order to shut them off when desired.

Coal-measuring devices consisting of chambers arranged in the chutes, and duly calibrated, are sometimes adopted as a rough guide to the amount of coal consumed on each boiler during specific lengths of time.

These coal measures are arranged to be worked by a chain and pulley, and are sometimes rotating and in other cases reciprocating devices. One motion opens the chamber at the top while the bottom outlet is closed, thus allowing a charge of coal to be admitted. The second movement of the chain closes the top opening of the chamber and opens the lower end, thus discharging the coal into the stoker hopper. An ordinary revolution counter is fitted to indicate the number of measurefuls of coal used in any given time.

With dry and "nutty" coal these measures cause a large quantity of dust to fly unless care is taken to keep the lower portion of the chutes full.

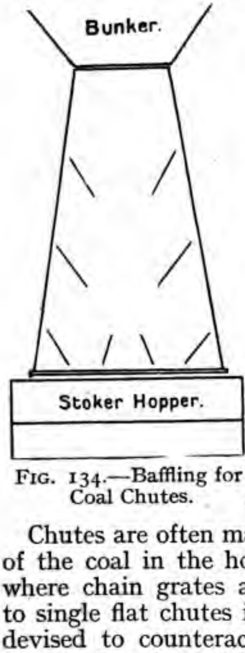


FIG. 134.—Baffling for Coal Chutes.

Chutes are often made bifurcated so as to obtain better mixing of the coal in the hopper, this being a most important matter where chain grates are in use. A method of baffling adapted to single flat chutes is shown in Fig. 134. This arrangement is devised to counteract the tendency of the larger constituents of mixed coals to fall to the outside of the chutes and hoppers. Care in keeping the hoppers and chutes well filled will also assist in mixing the coal.

Separate elevators, as shown in Fig. 135, are often used for each boiler where overhead bunkers cannot be utilised, but is not recommended otherwise, as this arrangement is not economical of power.

4. *Removal of Ashes*

In addition to the various coal conveyors already described as being equally useful in the removal of ashes, there is a type of ash-removal plant which is rapidly finding favour in large installations and utilises the air suction of a powerful blower for its motive power.

The Imperia system of removing flue dust has already been described in Chapter XIV, and a somewhat similar principle is utilised in the Babcock and Wilcox and the Bennis suction ash plants.

The apparatus consists of a rotary blower or exhauster drawing a continuous and large current of air through a line of cast-iron pipes. These pipes are laid adjacent to the ashpits, flue doors and other points whence ashes are to be removed, where also suitable openings are provided into the pipes for the ashes to be raked in.

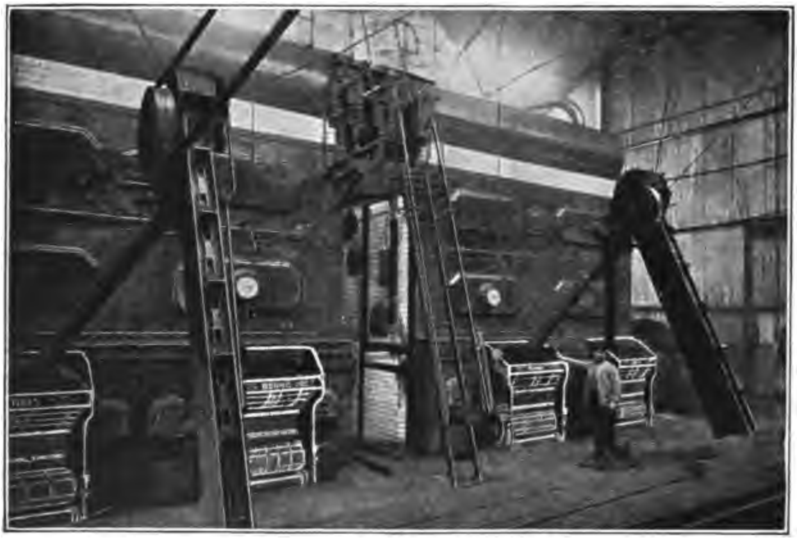


FIG. 135.—Coal Elevators for Individual Boilers.

The ashes falling into the current of air, are carried along at high velocity into the side of a large receiver which is inserted in the exhauster circuit. Here they lose velocity, are damped with a spray of water and fall to the bottom of the receiver, the air being extracted from a baffled opening at the top. The air is finally discharged through the exhauster into the atmosphere.

In order that this system shall work properly, certain precautions must be observed.

1. The ashes and flue dust must be dry when fed into the pipes, or clogging up may result.

2. The clinkers must be broken up to such a size that will pass an iron grid with 1½ in. openings.

3. The exhauster must not be stopped or the air current otherwise interrupted unless the ash pipes are clear. If this is not done the ashes will fall to the bottom of the pipe and also at the bends, and will require clearing out before the plant will operate properly again.

It is as well to instal an electrically driven clinker breaker, specially constructed for this work, and a great deal of inconvenience and labour will be avoided thereby.

A Bennis Ash Suction Plant is shown in Fig. 136, the illustration giving a clear idea of an arrangement with two receivers.

These receivers may be mounted over a railway siding, cart road or any other convenient place where it is desired to discharge the ashes.

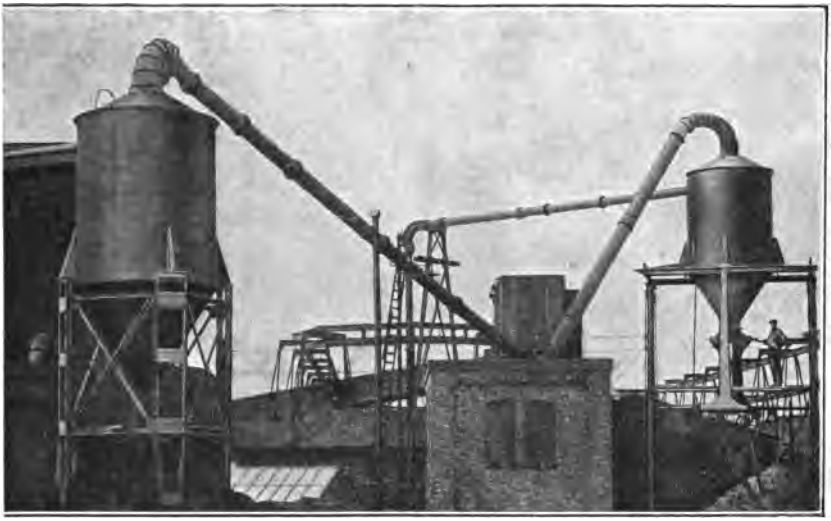


FIG. 136.—Bennis Ash-suction Plant.

5. *Storage of Coal*

In considering arrangements for storage of coal certain factors require attention.

The first point is that of convenience and ready transport from storage to the place where the coal is to be burnt. This will be determined by the space available and the general situation of the works and boiler-houses.

In selecting a position for coal bunkers or other storage arrangements, a very important point is the effect it will have as regards the "weathering" or slow oxidation of the coal, as well as the liability to heating and spontaneous ignition.

Slow oxidation is practically the same as low-temperature combustion, which is accompanied by more or less waste of the heat value of the fuel.

Without any appreciable rise of temperature, it has been found that a loss in calorific value of as much as 40 % of that of the newly delivered coal may result through storage for a lengthy period of time.

Where coal is stored in stacks of large bulk and depth the heat caused by the slow oxidation is not dispersed readily into the surrounding atmosphere, and therefore the temperature of the heap will rise. This rise of temperature accelerates the rate of chemical action that is taking place, with the cumulative result of a rapidly increased rate of temperature rise.

In time the temperature reaches the ignition point of the coal, and active combustion commences.

With the exception of anthracite and semi-anthracite, all coals are more or less liable to oxidation, heating and ignition during storage, especially dust and slack coals.

With larger-sized coals, superficial oxidation takes place, but the heat generated is carried away by the air-circulation which is present, due to the more open nature of the coal heap. As air circulation is impossible with slack coals, the cumulative effect of the heating has full scope, which accounts for the greater liability to fire.

Bunker fires are most likely to occur where the storage space is exposed to external heating, and also where the coal is in contact with wood. Exposure to changes of atmospheric conditions, such as alternating powerful sunshine and rainfall, also aggravate the tendency.

Overhead bunkers for gravity feed to mechanical stokers should be so constructed that pockets of stagnant coal are not formed, as these are sure to fire sooner or later.

Timber partitions, walls, etc., should be avoided, as the ignition point of wood is considerably lower than that of coal. Numerous bunker fires have been definitely traced by the author to the presence of timber accidentally left in coal bunkers.

Where coal is to be stored for a considerable period it is best to drive a number of perforated pipes into the heaps, with the upper ends left open. These pipes serve to ventilate the coal stacks and also provide a means of inserting a thermometer to ascertain the temperature of the centre of the heap. Should the temperature reach 120° F. the coal stack must either be used forthwith for firing purposes, or else trimmed over entirely by hand so as to cool it down.

Coal stacks (especially of small coal) should never be more than 8 ft. deep and only of moderate area, so that the effect of a fire will be localised.

Coal should always be stored under cover so as to moderate the effects of atmospheric changes. The first cost of such precautions will be repaid many times over by the better maintenance of the calorific value of the coal, even if no actual ignition takes place.

As far as possible the storage of coal for any length of time is to be avoided; the best arrangement, where circumstances will permit, being to put all fresh deliveries of coal into storage and work with the coal that has been in hand for the longest period.

This method has been utilised in some of the larger modern power stations by the arrangement of large capacity bunkers arranged so that any one of them can be drawn on for the whole fuel supply at any time.

Another method adopted is to submerge the coal in large tanks of water, which by its exclusion of air preserves the fuel against oxidation.

Although steel bunkers are very largely used for coal storage, they require considerable attention in the way of protection from the corrosive action of moist coal. This is usually dealt with by tarring the inside of the bunkers or frequent painting. These coatings never last for any satisfactory period, owing to the friction of the coal removing the paint or tar.

For bunker construction, reinforced concrete cannot be equalled, and should be finished smooth on the inside, without any recesses or projections that may retain the coal or impede its movement.

Summarised, the points to be borne in mind when arrangements are to be made for storage of bituminous coals are—

1. Freedom from exposure to external heat.
2. Absence of pockets for the accumulation of masses of coal dust.
3. Protection from the effects of atmospheric changes.
4. Ready accessibility for removal.
5. Ample means of ventilation.
6. Protection from dampness.

CHAPTER XX

STAFF OF BOILER DEPARTMENT.—Training and qualifications—Duties —Hours—Accommodation—Payment—Bonus schemes.

IN order to correctly visualise the importance of the boiler-house in any works, it is necessary to look upon it in the light of a self-contained factory for the manufacture of heat from the raw material—coal, the heat being delivered by the agency of steam to the various departments of the works to which the boiler-house is attached.

Taking an average battery of ten Lancashire boilers, working with economisers, it will probably be found, on carrying out a careful test by a thoroughly qualified specialist, that the efficiency does not exceed 60–65 %. Working a double shift such a battery will consume about 300 tons of coal per week. Operating under modern conditions with proper attention, the efficiency should be at least 75 %. The saving due to increasing the efficiency from 65 % to 75 % represents a saving of 40 tons per week or 2000 tons per year of 50 weeks. At 25*s.* per ton this shows a possible economy of £2500 per annum.

The average efficiency of industrial boiler plants in this country does not exceed 60 %, and on a battery as described above an increase from 60 % to 75 % will result in a saving of 3000 tons of coal or £3750 per annum.

The prevailing low efficiency of steam-raising plants is principally due to the neglect to provide suitable skilled supervision of the working of the plant together with insufficient care in the selection and training of the firemen.

Even with a properly trained staff the best results cannot be obtained without proper appliances or "tools of the trade," the shovel, steam gauge, and water gauge alone being hopelessly inadequate to meet modern requirements.

In engaging a proper staff for a boiler-house the first consideration is a competent specialist engineer, who should be held responsible for the efficient and economical working of the plant.

The training of such a Superintendent should be primarily that of a practical engineer. In addition a good general knowledge of chemistry, with specialised study of the principles of combustion of coal, general physics and mechanics are essential. He should be well versed in the proximate analysis and calorific testing of coal. Knowledge of the operation of bomb calorimeters is indispensable.

In order to obtain successful results the Superintendent should cultivate a power of simple and clear explanation of the phenomena that occur in connection with boiler firing, so that he will be able to educate the firemen to their work. Tact and ability in the handling of subordinate staff and workmen are also indispensable qualifications.

The duties of the Superintendent should be to take full control of the working of the boiler plant; to organise and appoint subordinate staff; to direct the working arrangements, record keeping and testing of the plant; to advise upon the purchase of fuel with regard to laboratory and working tests; to advise upon the purchase and installation of new plant and appliances; and to be generally responsible for the maintenance, cleaning and satisfactory operation of the boilers and accessory apparatus. He should also furnish a comprehensive periodical return of working costs in fuel, labour, repairs, maintenance and salaries per lb. of steam generated and number of heat units delivered.

In larger installations of boilers and furnace plant, say of twenty boilers (or their equivalent in furnaces) upwards, the appointment of three shift engineers, each to take an eight-hour shift, will be justified.

The training of such charge engineers should be that it will eventually fit them to become superintendents in their turn. The appointment of these assistants should be in the hands of the Superintendent, who should base his selection upon the interest the men appear to have in the special branch of work which they are to undertake, together with their general practical experience and scientific abilities.

By the engagement of these men a suitable continuous technical supervision will be ensured, which is the only satisfactory means of maintaining highly efficient operation throughout the twenty-four hours.

The duties of the shift engineers will be to supervise the firing of the boilers, keep observation upon the recording and indicating apparatus, and direct the firemen accordingly; to maintain discipline; to keep a record in the form of a log-book of all defects, repairs, special observations and remarks, results obtained, etc., during their respective shifts; to see that firemens' log-sheets are correctly kept; to supervise repairs and assist where required with trials and tests; to make examinations and reports on the state of boilers and brickwork.

Where the size of the plant is such that the general duties of the Superintendent will not allow him to carry out the laboratory work personally, the services of a chemist should be obtained to undertake such operations as the testing of coal, analysis of flue gases, calibration of recording instruments, feed-water testing and treatment, etc. In order to preserve systematic working the chemist's operations should be generally directed by the Superintendent.

In the majority of power-station plants the above technical staff, together with any further unskilled assistance found to be necessary, will be all that is required.

In the larger manufacturing works where the batteries of boilers may be scattered over a very wide area, it is probable that the Superintendent will find that a properly qualified assistant engineer is necessary, especially as it is in these scattered plants that the lower efficiencies are most likely to be found. The assistant should be obtained from the more promising of the shift engineers, and should be capable of acting as a deputy for the Superintendent during his absence.

It may be taken that about thirty boilers is about the limit which should come under the supervision of one shift engineer, and in those large undertakings where this number is exceeded, the work should be divided between two or more sets of shift engineers as required.

The working staff will consist of the following men, who will work to the instructions of and under the supervision of the shift engineer—

Leading Firemen.
Firemen.
Ash Wheelers.
Leading Boiler Cleaners.
Boiler Cleaners.
Leading or Foreman Fitters.
Fitters.
Fitters Mates.
Pipe Fitters and Mates.
Pipe Coverer and Mate.
Labourers and Cleaners.

Leading Firemen are each responsible on their shift for the firing of the boilers, maintenance of steam pressure, keeping of the firemen's log-sheet, notification of defects, cleanliness of boilers externally, etc.

They should be specially selected men of high intelligence and trustworthy, and also capable of seeing that their instructions are carried out by the firemen. These men must be sufficiently reliable to entrust with the charging of steam mains and similar work needing special care.

Too much care cannot be exercised in the selection of good *firemen*, as the efficient operation of the plant is largely dependent upon the manner in which they carry out their work.

Ash Wheelers are classed as unskilled men and as such need no special comment.

Leading Boiler Cleaners take charge of the boiler-cleaning gangs and are responsible for the thorough cleaning internally and in the flues of the boilers as they are laid off for the purpose. They must be conscientious and trustworthy men who know how to make their gangs work to their best ability. As the cleanliness of boilers has a very important bearing upon the cost-sheet, due care must be exercised in engaging both leading and ordinary boiler cleaners.

As regards *Boiler Cleaners*, it is as well to remember that small "wiry" and muscular men are the best for the class of work in question, as the bigger a man is, the more difficult he finds it to work comfortably in the somewhat confined spaces of a boiler and its flues.

Leading Fitters, Fitters and Mates for boiler plant should be men who are used to this particular class of maintenance work, as they are then more likely to appreciate the special points that may "crop up" than an ordinary bench fitter. As a rule, anything that lends itself to rapid and satisfactory completion of repairs will result directly or indirectly in economies in fuel consumption where steam-supply installations are concerned. Thus a man who does not require minute instructions how to proceed is greatly to be preferred.

Pipe Fitters and Mates require no special comments beyond those mentioned in connection with fitters.

It is as well, wherever the size of the installation justifies it, to engage a skilled *Pipe Coverer* to maintain the non-conducting coverings of the boilers, pipework, joints, etc., in good condition. Apart from the economy of this practice as compared with contract work in cost of covering alone, the amount of heat lost from uncovered hot surfaces will very possibly be more than that represented by the wages of a skilled pipe-coverer, if various portions are damaged and left uncovered until a sufficient amount of work has accumulated to justify a contract being placed.

The number of labourers and cleaners employed depends upon the size of the plant.

It is a good practice to employ steady youths on general cleaning work on boiler plants, and at the same time educate and train them to the duties of firing. This is the system utilised in training men for locomotive work on the railways, and leaves little to be desired in the way of obtaining efficient workers.

Hours of Work

As the operation of boiler plant is one of those trades that does not permit of "breaks" for meals, it is impossible to expect the men employed to work efficiently and take an intelligent interest in their work when the shifts exceed eight hours at a stretch.

The system of three eight-hour shifts has been recognised as the longest consistent with satisfactory results by electric power undertakings from the time of their first introduction, whereas in the manufacturing works the two-shift system of eleven hours on "days" and thirteen hours on "nights" has been the general rule. This can only result in the work being mere soulless drudgery with corresponding wasteful results in fuel consumption.

Another matter that should receive the earnest attention of every employer is the matter of reasonably decent accommodation for his boiler-house staff. As it is necessary to obtain the best and most intelligent class of men for firing, the conditions under which they will be required to work should be such that will attract the sort of men that is desired.

Every boiler plant should be provided with a bath and other proper washing facilities, and also a dressing-room where the men may change and keep their clothes; if this latter is provided with a table and benches for taking necessary food, and commands a good view of the boiler-house, it would provide the reasonable amount of comfort which any self-respecting man has a right to expect.

If any really satisfactory progress is to be made in fuel economy on boiler and furnace plants the occupation of a fireman must, in future, be recognised as a skilled trade and rates of payment and wages graded accordingly. As matters stand at present the job of a boiler fireman is generally scorned by the rest of the workmen, and it is therefore not surprising that only a comparatively poor type of man is obtained for this work.

If a fireman is paid no more than an unskilled labourer and is provided with inferior accommodation, the employer has no moral right to blame the man for wasteful methods, as he is not paying for anything more than unskilled work.

The author, after many years of contact with and handling of power-plant men, unhesitatingly asserts that the boiler fireman who is a competent man is considerably the superior to an engine-driver, although the latter is customarily looked upon as the higher grade of worker.

It is the exception to find an engine-driver who is able to take indicator cards from his engine, while a fireman is expected to understand (and quite rightly) the meaning of CO_2 recorders, pyrometers and draught gauges.

It is nevertheless a fact that engine-drivers are almost invariably regarded in this country as the superior grade and are paid accordingly. In the United States the reverse is being recognised, and the order of promotion is adopted in some of the larger power plants by the boiler-house attendants being selected from the most intelligent and best class of engine-room men.

The engineer in charge of the boiler staff should endeavour to induce his men to attend classes of elementary instruction on fuel, combustion, steam and the instruments, etc., found in up-to-date power plants. Promotions should be based on the results of these classes combined with the intelligent application of such knowledge in actual practice.

Bonus Systems

Where an equipment of recording apparatus, water meters, etc., is installed, it is possible to institute a system of additional payment to the engineers and firemen, and in fact all the men concerned with the boiler plant, based upon the overall efficiency obtained.

To make bonus payments of this description upon the results in percentage CO_2 in the flue gases only, is not sufficient to ensure economical results, as there are so many other factors which go to determine the final efficiency.

With a high percentage of CO_2 in the gases the temperature of these may vary over a range of 400° F., there is also no check upon the amount of fuel wasted in the ash heap, both or either of which defects may lead to serious waste of fuel.

The only fair basis upon which to work a bonus scheme is to make reasonable additional payments in proportion to the thermal efficiency of the plant, as calculated from the coal consumption and calorific value, feed-water measurements and temperature, steam temperature, etc.

It is difficult to ensure fairness even under these circumstances unless there is responsible supervision to keep a watchful observation upon the methods of working.

The amount of payment will depend upon the price of coal, size of plant and other factors, so no hard-and-fast rule can be given.

As the efficiency of the plant depends upon boiler cleaners, fitters and others as well as the firemen, it is necessary to include all these men within the scheme.

CHAPTER XXI

ORGANISATION AND EQUIPMENT OF A MODERN BOILER PLANT.—Selection of site, plant, and accessories—Systems of record keeping and tabulation of results.

A POINT that it is impossible to over-emphasise in connection with boiler plant is that a parsimonious policy in the matter of outlay in initial expenditure and subsequent maintenance is certain to result in a waste of fuel, labour and other materials that will counterbalance the saving in first cost many times over.

This fact has been fully recognised in all those modern power plants worked under "up-to-date" conditions where overall thermal efficiencies average between 70 % to 80 %.

To obtain results approximating to the above the whole range of considerations from the first selection of site to the final questions of the disposal of ashes, provision for repairs and maintenance, etc., should be thoroughly investigated by an expert with wide experience in these matters.

The selection of the site for a boiler-house is determined by the following considerations—

1. Convenience of coal supply.
2. Location in regard to the works to which the plant is attached.
3. Water supply.
4. Disposal of ashes.
5. Availability of exhaust steam.

In the above considerations, although in no case can any hard-and-fast rules be given, there are several questions that must be taken into account, from the financial and economical viewpoints, that are often overlooked.

In regard to electric power stations the question of the position of the boiler plant is practically summed up by stating that it should back directly on to the engine-room or turbine-house so that the length of steam piping is no longer than can be avoided.

In manufacturing works of other descriptions, where one battery of boilers may be required to supply steam to several shops at varying distances away, the position of such plant must be determined after very careful study of the particular condition of affairs to be dealt with.

Taking the various points already enumerated, the first is—

Convenience of Coal Supply

Wherever possible, without prejudice to efficiency in other directions, the boiler-house should be located as close to the railway, canal or river by which the coal is carried as can be arranged.

The other factors to be taken into account are whether this will so lengthen the steam pipes connecting the boiler-house with the remainder of the works that the condensation losses are greater than those that would be entailed in the installation and operation of a coal conveyor or suitable telpherage system.

If a conveyor or telpher has to be installed in any case it will be found that it is best to instal the boiler plant as close to its work as possible, as the extra driving power necessary for a few additional yards of conveyor is very small indeed.

The second point in question is—

Location in regard to Works of which the Plant forms a Part

The question of length of steam mains is the principal matter to be dealt with in determining the actual location of the steam-raising plant.

Proximity of the boiler-house to a forge is to be avoided as far as possible, for the heavy concussion set up by the operation of steam hammers is sure to result in cracking of brickwork, with resulting high cost of repairs and wastage of fuel owing to air leakage.

In some cases a central boiler plant is the best and most economical arrangement, whereas in other situations it may be advantageous to subdivide the work between two or more batteries.

Before deciding upon the latter course the questions of increased cost of wages for firemen, delivery of coal at more than one place, necessity for a margin for reserve or stand-by at each place must be decided. Especially the last question needs careful thought, as with three separate batteries a boiler with banked fires may be required at each; while with one central boiler-house, only one stand-by boiler will be needed.

Haphazard guessing at the best course to pursue will, not improbably, lead to quite erroneous conclusions, and the final decision in the matters enumerated should only be taken after careful calculation of all the different factors involved.

Water Supply

Neglect in providing a suitable water supply for boiler feed has in innumerable cases been the cause of great expense in fuel consumption and maintenance charges.

Many general engineers or proprietors of works who, in the first instance, have fondly imagined that the water supply for their boiler plant was quite of a suitable quality for use direct, have been painfully disillusioned after a very short period of working of their boilers.

With the exception of the hot-well return from turbine condensing plant, heating apparatus, steam-pipe drains and other sources of distilled water, no water supply should be accepted as suitable for boiler use without a chemical analysis. It may be safely stated that few or none of the ordinary sources of water are entirely suitable for boiler feed without previous treatment.

This is especially true of water derived from wells, canals and rivers, the proximity of which have often been a decisive factor in the selection of a site for a boiler plant. In any case sufficient room should be allowed for a water-treatment plant, whatever the source of main or "make-up" supply may be.

Disposal of Ashes

The question of ash disposal when selecting a suitable situation for the boilers should be considered upon the same general lines as that of the coal supply.

Availability of Exhaust Steam

Owing to the very great economies possible by the utilisation of exhaust steam for feed-heating purposes, the availability of such a supply should be made use of wherever possible.

In many large works the exhaust from all the engines, steam hammers and other similar plant is collected into one main header which is very efficiently lagged with non-conducting covering. This steam is in some cases used to drive an exhaust steam turbine supplying electric current for the operation of fans, pumps and other drives, as well as for lighting purposes.

Where steam heating apparatus is installed, live steam should *never* be used, the only method consonant with modern standards of efficiency and economy being a system of exhaust steam heating.

The hot-well return from either an exhaust steam turbine or from heating apparatus is used for boiler feed.

Apart from heat economy in the actual use of the steam the systems suggested above require only the small treatment plant necessary to deal with the "make up" water. The tendency to scale in the boilers is thus reduced to a minimum.

Electric Power

An additional and important matter to take into account is whether a reasonably cheap supply of electric power is available for the driving of mechanical stokers, fans, conveying plant, etc., and also for lighting purposes.

It is difficult to run a boiler plant upon really efficient lines without the assistance of electric power, as steam and internal combustion engines cannot compare with electric motors as regards convenience and low-running costs.

CHOICE OF PLANT

The first consideration in selecting a suitable type of boiler plant is the quantity of steam that will be needed per hour at maximum demand.

With any size or type of boiler there is a rate of steaming that represents the highest efficiency obtainable in the particular unit adopted. This is the capacity usually given by the maker as the normal capacity of the boiler.

For average working conditions about 20 to 25 % should be deducted from the normal capacities given in the maker's list to arrive at the amount of steam that the boiler can be relied upon to deliver without forcing.

In addition sufficient excess capacity should be provided to allow for the largest boiler in the battery to be laid off for cleaning or repairs without necessitating recourse to the forcing of the remainder.

To meet varying conditions of demand for steam and at the same time to work the boilers at their best efficiency, neither forcing them nor working them so lightly that the grates are not sufficiently covered, two courses are practicable.

The first method is to instal a large number of small boilers so that those working can be closely proportioned to the demand. This way of meeting the difficulty is not to be recommended, being wasteful of heat by radiation owing to the large number of steam-pipe branches, valves and other fittings which are potential leakage points. The capital cost of such a battery of boilers would be disproportionately high, together with unreasonable maintenance charges.

The other and correct method of dealing with a widely varying demand is to instal a battery of boilers carefully graded as to steaming capacity.

To illustrate this system we may take as an example an engineering or other works requiring a maximum hourly steam-supply of 100,000 lbs. of steam per hour, which at times may fall to 10,000 or 15,000 lbs. per hour.

The boiler power required according to listed capacities would be 125,000 lbs. per hour, after allowing for 20 % reduction as already described.

A suitable battery of boilers for dealing with the demand would be as follows—

2 pairs (= 4) water-tube boilers at 25,000 lbs. each;
3 Lancashire boilers at 10,000 lbs. each;

giving a total evaporative capacity of 135,000 lbs. of steam per hour. All these boilers should be equipped with economisers and induced draught.

An economiser would be necessary for each of the water-tube boilers, with one induced draught fan for each pair.

One fan and one economiser would be installed to serve all of the three Lancashire boilers.

The advantages of such a composite system are that the Lancashire boilers provide the necessary reserve of steam to deal with sudden demands until the water-tube boilers are able to pick it up, which they will do very rapidly. The load should be carried as far as possible by the water-tube boilers because of their higher efficiency.

At a sudden fall of demand the water-tube boilers can be checked almost instantaneously by slowing down the fans and stopping the mechanical stokers. Under similar circumstances a battery of Lancashire boilers would blow off heavily for some considerable time.

Another advantage in favour of the use of water-tube boilers as far as practicable is the small ground space required as compared with Lancashire boilers of similar capacity. An installation as described would occupy about 2800 sq. ft. of floor space, whereas a battery of Lancashire boilers of the same total capacity would occupy 5430 sq. ft. or 94 % more.

With steady rates of demand such as for heating purposes, gas producers, etc., the advantage is with the water-tube boiler, as no sudden variations are likely to occur. Water-tube boilers are constructed for such low evaporative rates as 800 lbs. of steam per hour, with a heating surface to grate area ratio of 30 : 1.

These smaller water-tube boilers, however, do not compare favourably with the vertical multitubular types as regards ground space occupied, but will repay the difference in the greater efficiency obtained.

ECONOMISERS

Economisers should be installed with all except the smallest plants, and no battery of Lancashire boilers is an efficient job unless an economiser is included.

DRAUGHT

Again, excepting in the smallest plants, induced draught fans should be used in preference to chimney draught. The latter is a most expensive method of providing the necessary air supply to the fire-grates, as the heat required to provide the necessary draught pressure in a chimney of reasonable height may be anything from 22 % to 28 % of the total heat of the coal used.

FLUES

Ample room should be provided for the construction of sufficiently large flues, an error on the large side being preferable to undersized passages for the gases.

Reference should be made to the contents of Chapter XVIII, where the points bearing on economy and efficiency have been fully detailed.

Having made a satisfactory selection of a site and the plant to be installed with all due regard to probable efficiency and economy, it does not follow that the good results of which the plant is capable of showing will necessarily be obtained without any further provisions to this end.

The question of selection of staff and workmen has already been dealt with in Chapter XX, to which the reader is referred.

EQUIPMENT OF BOILER DEPARTMENT

In order that the firemen, engineers and others responsible may form an accurate idea of the results any boiler or battery of boilers are giving at any time, an adequate equipment of recording and indicating instruments is required. The absence of such devices leaves all those responsible for the plant absolutely in the dark as to whether wasteful or economical conditions are prevailing.

In the large majority of manufacturing plants it is an unfortunate fact, from the national interest, that the following illustrates the usual state of affairs.

A known quantity of coal is burned (more or less) under the boilers, the heat value of the fuel being quite unknown. This unknown quantity of heat is used to supply steam in unknown quantities and heat value to the shops requiring it. The works manager is quite unable to ascertain what the real value of the fuel he purchases may be, does not know how much of this value is utilised and how much is wasted either avoidably or otherwise.

It requires very little reflection to realise that by the use of suitable apparatus that will be a guide to obtaining good results at all times, it is only following the ordinary business methods observed in any factory which is worked at any degree of profit.

The proper modern equipment of a battery of boilers will now be given, and if this is carried out it will be possible to observe the working conditions in detail at any moment and detect any fault that may exist. All the necessary data will be provided for the calculation of the efficiency of the plant, and by its means the task of improving conditions or maintaining them at the highest standard of efficiency.

The diagrammatic outline plan (Fig. 137) of a battery of four Lancashire boilers, flues, economiser, fan, feed pumps, etc., shows all the points at which observations should be made, and the letters given in the following list of equipment refer to the corresponding points as lettered on the plan.

Each boiler should be fitted with the following instruments: in addition to the usual steam and water gauges (A).

D. Draught indicator connected near dampers with indicator at the boiler front.
B. Steam flow indicator mounted at the boiler front.
S. Steam thermometer (when superheaters are used).

Each battery of boilers should be fitted as follows—

H. CO_2 recorder connected to main flue.
K. Draught recorder connected to main flue.
F. Steam pressure recorder connected to steam main.
P. Indicating pyrometer connected to inlet and outlet flues of economiser, with spare connections for additional test points in boiler flues.

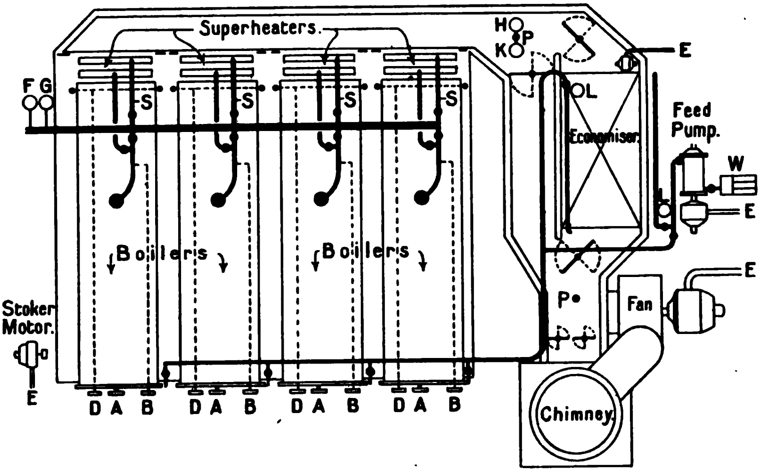


FIG. 137.

L. Recording thermometers, one each on inlet and outlet connections of economiser. The former may be inserted in pump delivery pipe.
W. Water meter.
E. Electricity meters on fan, pump, economiser and stoker drives.
G. Recording thermometer connected in steam main when superheated steam is used.

In addition to the above it is advisable to have one boiler equipped with its own water meter, CO_2 recorder, feed-water thermometer, etc., so that it may be utilised for the testing of sample trucks of fuel for contract and other purposes.

All the recorders and indicating instruments should be housed in a roomy cabin in which the log-sheets should be made up and kept. It will thus be possible for the engineer in charge to make a complete observation of all instruments and records in a very few minutes, which might not be done if the instruments were scattered throughout the boiler-house.

The outline sketch (Fig. 138) shows an arrangement of such instruments as described. It will be seen that separate recorders are provided for the feed-water temperatures. These readings may be taken on the pyrometer indicator if electrical thermometers are preferred for the water temperatures. Of course this latter arrangement would necessitate regular periodical readings being taken and entered on the log-sheet. Again, where the better system of a separate recorder is chosen, a double instrument recording both inlet and outlet water temperatures on one chart is very convenient. Such a double recorder is supplied by the Cambridge Scientific Instrument Co.

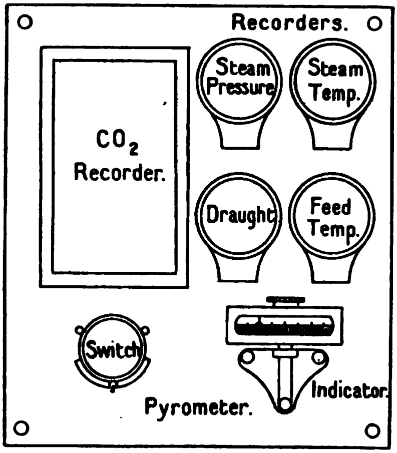


FIG. 138.

The next question in the matter of equipment is the provision of a suitable laboratory for the testing of fuel, water and gases. The essential conditions for the site of a laboratory are good lighting, freedom from vibration, supply of water, gas, and, preferably, also electricity and steam.

The apparatus necessary are as follows—

Chemical balance.
Bomb calorimeter.
Steam or water jacketed oven.
Gas burners and muffle.
Crucibles, dishes and other detail apparatus.
Coal-crushing and pulverising apparatus.
Burettes and reagents for water analysis.
Gas-sampling bottles.
Orsat gas analysis apparatus.
Portable pyrometers, thermometers, etc.

Other appliances for the use of the chemist upon the works are a 2 cwt. weighbridge for coal weighing, Barrus moisture calorimeter, tanks for feed-water measurement, etc.

A small electrically driven turbine pump mounted on a truck, together with a weir or notch type feed-water meter, is also to be recommended as a most useful piece of apparatus for employment on boiler tests.

A length of steam pipe draining into a receiver which is mounted upon a small weighbridge, together with the necessary thermometers, gauges, etc., is a desirable addition to the laboratory equipment for use in determining relative values of non-conducting pipe coverings, before adopting any particular variety for use on the steam mains or elsewhere.

In order that all the data obtained may be of use and available for ready co-ordination and analysis by the Superintendent Engineer, they must be methodically drawn up, so that he can make an accurate report on the results and state of his plant to the general management.

The first stage in the direction of the information required is the collection and systematic arrangement of the data collected in the boiler-house. In addition to the charts from the recording instruments the leading fireman should enter a log-sheet drawn up on similar lines to that shown in Fig. 139. From the charts and these sheets the shift engineer will be able to work out and enter up the engineers' log-sheet shown in Fig. 140; this should not form part of the general report book, but should be a separate sheet that can be filed in conjunction with the other forms and charts for ready reference.

The engineer's log-sheet, report book and the recorder charts are submitted to the Superintendent Engineer each morning, who will issue any instructions based on these reports together with that from the laboratory (Fig. 141).

Having now all the essential data before him, the Superintendent will be in a position to work out the figures required for his report to the management. The form of this report may vary in details from that given in Fig. 142, which, however, is a good example upon which to base the particular form finally decided upon. In fact, all the log-sheets and report forms will vary more or less according to the particular circumstances which exist in each individual plant.

It is only by running a steam-supply plant on systematic and business-like lines such as those suggested above that it can be made to compare favourably with other manufacturing plants, of which it is an example.

If, on examination of the data available it is noticed that certain points are not satisfactory, the scope of the records available render it a comparatively simple matter to determine with the closest accuracy the cause of and remedy for any such irregularity.

As regards the reports proper as distinct from the log readings, every encouragement should be given to all the staff concerned to make suggestions that will result in increased efficiency; and suitable recognition of such suggestions when found to be

BOILER HOUSE LOG SHEET.

Date 19 .

Shift— .m. to .m.

Boilers.

Boiler No.	Hours.		Blown Down at	Gauges Blown Through at	Safety Valves Tested at	Remarks and Reports.
	Working	Banked				
1						
2						
3						
4						
5						
6						
7						

Economiser.

Hours Working . Blown down at .m. Safety Valves tested at .m.

Remarks and Reports—

Feed Pumps.

No.	Hours Worked.	Remarks.

Fans.

No.	Hours Worked.	Remarks.

Hourly Readings.

Hour.	Water Meter.		Feed Temp.		Temp. of Gases.		Steam Temp.	Draught in Main Flue.	Remarks.
	Reading.	Difference.	Econr. Inlet.	Econr. Outlet.	Ent'ring Econr.	Leaving Econr.			
1									
2									
3									
4									
5									
6									
7									
8									

Men on Duty.

Leading Fireman.	Firemen.	Firemen.	Coal and Ash Trimmers.

General Remarks.

(*Signature*) ______________________

Leading Stoker.

Fig. 139.

BOILER DEPARTMENT.

SHIFT ENGINEER'S LOG REPORT.

To The Supt. Engineer.

Date 19 .

Shift— .m. to .m.

Coal Delivered.

Wagon No.	Owner.	Wagon No.	Owner.	Wagon No.	Owner.	Wagon No.	Owner.

Estimated Coal Consumption tons cwts.

Ashes Removed cwts.

Notes and Remarks on Coal

Water.

Consumption by Meter.	Average temp.		Evaporation per lb. of coal.		Factor of Evaporation.	Evaporation per Boiler Hour.		
	Econr. Inlet.	Econr. Outlet.	Actual.	From and at 212° F.		Actual.	From and at 212°.	
galls.								

Steam.

Average. Pressure.	Average Temp.	Average Moisture.	Specific Heat.	Superheat.	Total Heat.	

Gases.

Average CO_2	Average Temp.		Average Draught.			Loss in Gases.	
	Leaving Boilers.	Leaving Econr.	at Damp'rs	at Fires.	at Chimn'y		
%							

Electricity Consumed.

Lighting.	Pumps.	Stokers.	Economiser.	Fans.	Total.	

Boilers.

	Flues Cleaned.	Washed Out.	Off for Scaling.	Off for Inspection.	Inspector reqrd. for Boiler No. and date.
Nos.					

Total Boiler Hours—Steaming ; Banked .

Absentees—

Men on Duty.

Battery.	Names.

Remarks.

(*Signature*)

Fig. 140. Engineer in Charge.

BOILER DEPARTMENT.

CHEMIST'S WEEKLY REPORT

TO THE SUPT. ENGINEER.

Week ending, , 19 .

COAL.

AVERAGE TESTS

Name of Coal.	Calorific Value.		Proximate Analysis.						
	As fired.	Dry.	Moisture.	Vol. Matter.	S.	Coke.	Fixed Carbon.	Ash.	

SPECIAL TESTS

AVERAGE TEST OF ASHES—Combustible %. Ash %.

WATER.

DAILY TESTS.

Day.	Before Treatment.				Reagents Added.		After Treatment.			
	Temp. Hardness.	Perm. Hardness.	Total Hardness.	Total Solids.	Soda.	Lime.	Temp. Hardness.	Perm. Hardness.	Total Hardness.	Total Solids.
Sun.										
Mon.										
Tues.										
Wed.										
Thur.										
Fri.										
Sat.										
Aver.										

SPECIAL ANALYSIS.

TESTS OF FLUE GASES.

INSTRUMENTS CHECKED.

(*Signature*) ____________________

FIG. 141. Chemist.

BOILER DEPARTMENT.

SUPERINTENDENT ENGINEER'S WEEKLY REPORT

To The General Manager.

Week ending, 19 .

Total Coal Consumed . . tons cwt. qrs.
,, Water Purchased . . . . galls.
,, Current Consumed . . Lighting units.
,, ,, ,, . . Power ,,
,, Cost Salaries and Wages . . . £ s. *d.*
,, ,, Materials, R. and M. . . . £ s. *d.*
,, ,, Rent, Rates and Taxes . . . £ s. *d.*
Average price of Coal per ton . . . . £ s. *d.*
Price of Water purchased . . . *d.* per 1000 galls.
,, ,, Electricity for Lighting . . . *d.* per unit.
,, ,, ,, for Power . . . *d.* ,, ,,

Average cost of evaporating 1000 lbs. of water—

	£	*s.*	*d.*
Coal			
Water			
Electricity . . .			
Salaries and Wages . .			
Repairs and Maintenance .			
Renewals and Depreciation			
Rents, Rates and Taxes .			
Removal of Ashes . .			
Total . .			

Thermal efficiency of plant . . %

Losses—
In Flue Gases. . . . %
,, Moisture . . . . . %
,, Radiation . . . . %
,, Ashes . . . . . %
Unaccounted for . . . . %
Total . . 100 %

Signature ______________________

Supt. Engineer.

Fig. 142.

of practical utility should always be made in the form of a gratuity proportionate to the economy obtained.

It is important to gain the confidence of the men by demonstrating that all these efforts towards economy tend to the reduction of the manual labour required without lessening the number of men employed, thus identifying the interest of their employers and their own as one and the same thing.

The Superintendent should make it a part of the routine work to have an informal conference at regular intervals of, say, once a month, with his assistants, where any suggestions as to improvements in operation, new appliances and other matters bearing upon the efficiency of the department may be fully discussed. The less formal this conference is made the more likely is it to be productive of useful results.

Repairs and Maintenance

The boiler department should be entirely self-dependent as regards all matters pertaining to the repairs and maintenance of boilers, pumps, steam mains and all other plant and appliances. It is only by this means that certainty of rapid repairs can be secured.

The equipment of a repairs section should consist of a roomy fitting shop with a lathe of sufficient size to accommodate the largest jobs the shop can possibly be called upon to carry out. A small lathe for skimming up valves, etc., a drilling machine, valve seater and emery wheels, together with the usual benches and vices, complete the essentials.

It should be made a rule that a duplicate of every fitting used should always be in stock and in good condition, ready for immediate fitting into position when the necessity arises. The faulty fitting is then sent into the shop for overhaul and repair, and when this is completed put into stock to replace the one removed.

As delay in carrying out repairs may cause serious interruption to the work of the shops concerned with possible considerable loss of fuel, this need for rapidity cannot be too emphatically insisted upon.

CHAPTER XXII

REHEATING FURNACES.—Principles governing firing—Special points to be observed—Fire-grates and mechanical stokers—Dampers and air supply--Waste-heat boilers.

THE question of the firing of reheating furnaces is practically identical with that of boiler operation, and therefore where boilers and furnaces exist together in one works, as is usually found, the supervision of the furnace firing work should be combined with that of the boiler department. This is especially true where waste-heat boilers are used in conjunction with the furnaces, which should always be the case except with continuous working furnaces; in these the exit temperature of the gases is so low that no heat is left over in sufficient quantity for steam-raising purposes.

The outstanding point of difference between a reheating furnace and a boiler is that in the former there are definite limits of temperature to be worked to, or the quality of the resulting forgings may be seriously affected. Another important factor is that the work done by the furnace and forge hands is usually paid for on a tonnage or piecework basis. The requirements, therefore, are rapid and uniform heating to the required temperature (which will vary in different shops and with different classes of steel), the size and shape of the billets and forgings also having a very considerable influence upon the heat conditions.

The emission of smoke from furnace chimneys has been considered to be a necessary evil. This is by no means the case, and indicates an avoidable waste of fuel equally as much as smoke issuing from the chimney of a boiler-house.

The principles which govern the economical firing of these reheating and similar furnaces are precisely the same as those involved in boiler firing.

The causes which are in the main responsible for the great waste of coal taking place in furnace plants are—

Unsuitable design of fire-grates.
Entire lack of skill on the part of the firemen.
Prejudice against modern methods.

A very common type of fire-grate is shown in Fig. 143, and consists of a number of square section rolled bars placed loosely upon two or three transverse bearer bars. This arrangement is constructed so that the grate level is just below the underside of the sill plate, so that fire-bars may readily be renewed from beneath the plate without having to open the fire-door.

It is difficult to conceive of a more crude or inefficient form of grate than that described above. The fire-bars if arranged regularly upon the bearers only permit of about 30 % effective grate area. If, as is usually the case, the bars lie anyhow on the bearers, some of them will be close together and others anything up to two inches apart. The result is that at the places where the bars are bunched the coal is only coked and does not burn away, and is withdrawn at cleaning times incompletely consumed. At those places where the bars are far apart the smaller portions of the coal fall into the ashpit as soon as it is thrown on the grate.

The position of the grate below sill-plate level, also, does not permit of efficient slicing of the bars.

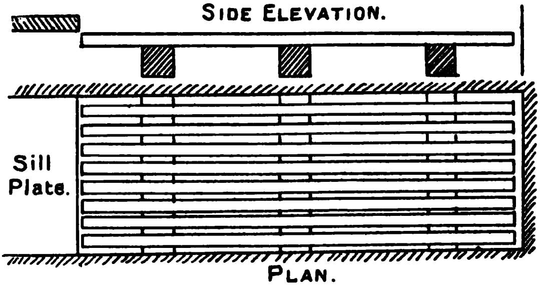


Fig. 143.—Common Type of Furnace Fire-grate.

The obviously correct method of construction is to fit such furnaces with fire-bars designed upon those principles that are observed in well-arranged boiler plants, so that approximately 50 % effective area is obtained. The bars also being evenly spaced and unable to be moved laterally, ensure that the air is evenly distributed, resulting in more complete combustion of the coal.

The improved description of fire-bars are best arranged with their upper surface level with the sill plate to assist in slicing and cleaning out. This will probably need some rearrangement of the bearers.

The practice of employing the man who fires the furnace to assist in the forging work is quite antagonistic to all ideas of economy, as the proper management of fires requires the whole and undivided care of their attendant.

Men engaged for furnace firing should be carefully selected in the same way as boiler firemen for their intelligence and aptitude for the special requirements. Instead of this being the usual practice, the firing is usually carried out by a man of no particular intelligence, who looks upon the job as an unpleasant one that should be done as infrequently and rapidly as possible, without prejudicing the amount of work turned out by the gang of which he forms part.

The usual result is that fires are piled up as high as possible, often by means of a rake, and the whole air supply applied to get sufficient heat. The air supply is usually left absolutely unregulated according to the thickness or state of the fires.

Fires are kept working at full thickness to within a short time before the shift is completed, when the whole fire is raked out bodily and the bars are cleaned. This process is followed by filling up the grate again with a large quantity of fresh coal, which smokes heavily for a considerable time before becoming ignited by the surrounding red-hot brickwork, but as the air supply is usually kept shut off until the next shift comes on so that the fires are ready to be started "full blast" at once, the waste of heat is very great indeed.

The practice of keeping heavy fires in the furnace and then, at the last moment before cleaning out, quenching the fire with a stream of water, or "hosing the fire-box" as it is termed, is very widely adopted. The results are that large quantities of unburnt coke and coal are drawn out and thrown on to the ash heap; the fire-brick linings of the furnace are seriously damaged, necessitating frequent and expensive repairs and renewal; the cast-iron casing in the vicinity of the firing door is often more or less fractured. This practice is, of course, mainly due to the piecework system, causing the men to resort to the most rapid means of cleaning the fires without previously "burning down" to a sufficient extent.

The actual design of the furnace itself will, of course, have a considerable bearing upon the fuel economy, but if the points dealt with above are remedied alone, a very great advance will be made in the fuel economy of iron and steel works.

Summarised, the steps to be taken are—

1. Perfection of the fire-grate construction.
2. Careful selection of firemen, who must not have other work to perform.
3. Proper technical supervision of the firing.
4. Correct regulation of air supply to the fires.

In certain steelworks very large economies in fuel have been obtained by the substitution of mechanical stokers in place of hand firing for reheating furnaces.

There is no doubt whatever that if the scientific principles, now being more generally recognised as essential for obtaining satisfactory results in connection with boiler plants, are also applied to furnace work, enormous economies will result in the national coal consumption.

Under correct conditions combustion of the fuel should be complete by the time the gases reach the exit ports of the furnaces, but as the conditions necessitate the maintenance of a high temperature throughout the furnace proper, the gases will leave it at a very high temperature, usually about 1800° F. It is owing to this necessity of protracted combustion, especially in large furnaces, that long-flame coals are the most suitable.

In order to utilise the heat that is generated more completely, what are known as continuous working furnaces have been designed. These furnaces are of considerable length, with a bottom or hearth which slopes from the chimney end towards the fire-grate. The billets, etc., are fed in at the upper or " cold " end nearest the chimney, and are withdrawn for forging at the lower or " hot " end nearer the fire-grate. Apart from the better utilisation of the heat, which may be reduced to 500° F. before it reaches the chimney, the advantages of more even and gradual heating of the steel are of great importance. This system, however, only lends itself conveniently to such cases where all the work is of a similar character, and is also of such a shape and weight that can be readily moved down the sloping floor of the furnace.

Apart from such continuous furnaces, no reheating furnace can be considered as an efficient piece of plant if the gases are allowed to escape to the atmosphere without a further utilisation of the remaining heat.

WASTE-HEAT BOILERS

Practically every ordinary type of boiler is suitable for the purpose of generating steam from the heat available in the exit gases from furnaces. The only difference is, that the gases are led into the boiler where the grate is situated in the case of a coal-fired boiler. As combustion should be complete before the gases leave the furnace, no special brickwork combustion arches, etc., are necessary.

As the supply of heat available will depend upon the size of the furnace and other factors, a method of calculating the evaporative capacity that may be expected is given here.

Let—

C = lbs. of coal burnt on the grate per hour;

H = Total heat of steam per lb. at required pressure in B.Th.U.;

G = Temperature of waste gases in ° F.;

S = Steam available per hour in lbs.;

then—

$$S = \frac{C \times 21 \times (G - 450 \times \cdot 24)}{H.}$$

Having ascertained the amount of steam that should be obtained by use of the heat of the waste gases, the selection of a suitable boiler is the next step to be taken.

As the temperature of the gases is low as compared with direct coal-fired boilers, the essential feature of a waste-heat boiler is a large heating surface ratio to the volume of water contained in it. Thus most forms of horizontal and vertical cylindrical multitubular and also water-tube boilers comprise the most satisfactory types of waste-heat boilers.

For small furnaces and low evaporations the Cochran boiler is very widely used on waste-heat installations.

For somewhat larger jobs small Stirling or Babcock boilers are useful, and also the horizontal multitubular boiler works well, with the advantage of simplicity of design and easy cleaning of the tubes.

Although these cylindrical multitubular boilers are somewhat dangerous for use when externally coal fired, they are perfectly reliable for waste-heat work owing to the heating being quite uniform. The waste gases are merely passed through the tubes directly without any preliminary high temperature external application to the lower portion of the shell, as is the case with coal firing. The direct path of the gases is also an advantage as it avoids undue interference with the draught.

In the largest installations of boilers fired with waste gases from reheating furnaces, water-tube boilers are invariably used.

As already mentioned, combustion should be complete before the gases enter the exit flues of the furnace. If this is actually the case the small tube multitubular boiler can be relied upon to give very satisfactory results. But as the production of smoke, due to incomplete combustion, is only too frequent on account of the crude methods of firing and fire-grate construction, a large proportion of the advantages of waste-heat boilers is lost. The tubes become rapidly choked with sooty deposit requiring frequent—sometimes daily—brushing through with loss of heat from this cause, as well as through reduced heat transference. Water-tube boilers are not so readily affected by these bad firing conditions. As the fault lays, not in the boiler but in the firing, the remedy is to correct the latter defect.

The testing of the flue gases for CO_2 and with the pyrometer is as essential in connection with furnace work as in the case of boilers, if careful observation is to be kept upon the satisfactory operation from the economical standpoint.

Where waste-heat boilers are in operation great care should be taken to exclude any indraught of air through the damper slots. Waste-heat boiler makers state that there should be no dampers or alternative exit to a chimney. If this advice is followed there is always the risk of the furnaces being put out of action due to failure of the boiler from any cause, and as this would seriously interfere with the work of the shop, the author is unable to endorse this advice.

The temperature of the waste gases entering the boiler should not exceed 1800° F., and 500° F. leaving the boiler. CO_2 should be maintained as high as possible from the furnace to the boiler chimney.

Where the waste heat is insufficient alone to supply the steam required, an auxiliary coal fire may be added to the boiler to "make up." In this case the boiler is arranged somewhat higher than for waste-heat firing alone, and the hot gases are brought in from the sides above the coal fire-grate.

In connection with waste-heat boilers, the installation of automatic feed regulators is of great advantage, as it is usually difficult for the attendant in charge of a number of boilers to keep a constantly correct level of water by hand. This is especially the case when the boilers are numerous and widely scattered.

WASTE-GAS BOILERS

These are ordinary type boilers fitted with additional burners for the use of such waste gas as that of coke ovens, blast furnaces, etc. With these burners the ordinary fire-grate is usually retained, and thus provides for a supplementary coal fire should the supply of gas be diminished or fail altogether at any time.

PRODUCER GAS-FIRED FURNACES

Although firing of furnaces with gas instead of by coal direct should give perfect combustion, this is far from being the case in actual practice. Sometimes it is the initial design that is at fault, and in other instances the potential efficiency is not obtained owing to carelessness or ignorance in operation.

Taking the design to begin with, it must be borne in mind that the mere "throwing together" of gas and air, even in the correct proportions, does not necessarily result in complete combustion where and when required. In fact it is difficult to cause two gases of very different densities to mix readily unless special precautions are taken to this end.

With long furnaces requiring even heating throughout, intimate mixture of the air and gas in the first instance is not desirable, as this will cause rapid localised combustion. For continuous working furnaces, where the end at which the charges are fed in is required to be comparatively cool, the high local temperature is desirable, and therefore the gas and air should be intermixed by the use of numerous small parts instead of fewer parts of larger size.

If combustion is only partially completed in the furnace, it will continue in the exit flues, where the air and gas are brought closer into contact, with possible specially active places at bends or other points where eddying takes place.

It is equally true of furnace work as with boilers that the use of a high chimney temperature in preference to an induced draught fan is a most uneconomic procedure, and therefore the heat should be utilised to its utmost before discharging the gases into the atmosphere. With high flue temperatures waste-heat boilers should be installed, while with lower temperatures economisers for boiler feed or heating apparatus will serve to reduce the waste of heat.

Although not often applied in this connection, there is no doubt that the use of CO_2 recorders and pyrometers for the flue gases of furnaces should be more generally adopted. Intelligent use of these appliances should go a long way in the reduction of the coal bill.

CHAPTER XXIII

MISCELLANEOUS FUELS.—Briquettes, coke breeze, dust fuel, oil, refuse, etc.—CONCLUSION.

THERE is no doubt that there is a vast quantity of material at present thrown away, which would make excellent fuel if treated suitably or burnt in specially constructed furnaces.

Although on the Continent the practice of briquetting the fine dust of coal or coke has found favour for many years past, the briquetting industry has made comparatively little progress in this country.

The process of briquetting consists of mixing a quantity of coal or coke dust with a suitable binder, such as tar or pitch, in a molten state. The hot mixture is moulded in a press into small blocks about three inches to four inches cube and set aside to cool.

By this means the fine coal dust, etc., which it would be quite impossible to burn upon a grate in the ordinary way, can be made up into a form which is fired either alone or mixed with coal.

With highly bituminous coal dust the admixture of a separate binder is sometimes unnecessary, the tar in the coal itself being sufficient to bind the dust when heated and pressed.

Briquettes made from other than bituminous coals, and also from coke dust, become very brittle on the fire-grate after the binding medium has distilled and burnt out, and should not be touched until they are completely consumed. It is advisable to burn these non-bituminous briquettes under a strong draught and consequently rapid combustion conditions.

Coke dust or breeze can be burnt successfully upon specially constructed grates with very close fire-bars, and a correspondingly strong forced draught with an ample additional supply of pre-heated air over the fire-bed. The fire must be kept highly incandescent, for if it be allowed to die down by reducing the draught, difficulty will be experienced in regaining the higher temperatures.

A method of burning coke breeze together with small coal is by the use of chain-grate stokers fitted with a double hopper, the section of the hopper nearer the boiler itself being fed with the coal, and the front portion of the hopper using small coke. The coal is thus fed in a layer upon the coke, and each is adjusted for thickness by its own door so that the best conditions may be obtained.

Finely pulverised coal is used as a very efficient fuel by injecting it by means of an air blower into the boiler furnace, where almost instantaneous combustion takes place, especially if the air and pulverised coal are correctly proportioned. This method practically amounts to a form of gas firing.

One drawback to the above dust-firing process is that the ash formed is so light that it is not deposited in the flues, but is carried out of the chimney and deposited in the form of a grey impalpable powder over the surrounding property.

Theoretically speaking, the pulverised fuel furnace is perfect as a coal-consuming device, and very high efficiencies indeed have been obtained with specially constructed boilers, built for this purpose.

Oil fuel at present cannot compete with coal on account of its high price in the United Kingdom, but the incidental expenses of attendance, removal of ashes, maintenance, etc., are so low compared with coal, that the difference in total cost of oil fuel burning is not so great as would appear at a casual glance. The cleanliness also of oil-fuel installations is a great point in its favour.

The efficiency of oil as a fuel depends almost entirely upon the design of the burner or "atomiser" used, the object being to obtain the spray in as fine a state of division as possible. The greater the degree of atomisation obtained the better will be the resulting efficiency.

Refuse generally has not a high calorific value, but nevertheless no combustible matter should be aimlessly burned, but should be destroyed in a properly constructed destructor, the gases from which may either be passed through a boiler specially installed for the purpose (preferably of the water-tube type), or fitted with an auxiliary fire-grate below the destructor gas ports for burning coal in addition.

Such a boiler, if of insufficient capacity alone, should be coupled to the remaining coal-fired boilers, and if used in this manner will effect a very marked reduction in the fuel consumption.

CONCLUSION

HAVING now reached the end of this small effort to draw the attention of works managers and engineers to the possibilities of that "Cinderella" of most manufacturing concerns, the boiler-house, the author wishes it to be understood that he is not unmindful of those working conditions which exist in many factories that make high efficiency practically unobtainable.

The fact that the demands for steam vary over a wide range and at regular intervals should not, however, be made the excuse for neglect to improve the efficiency of the plant by every possible means, even though the final result may be far from perfection.

Even in the most highly organised and best equipped plant in existence there is even room for some further economy over those obtaining at present, and it stands to reason that where the matter of efficiency has received little or no skilled and trained attention the scope for reduction in fuel consumption will be very wide.

In any case the old saw that "mony a mickle maks a muckle" is exceedingly true of steam plants, and in these days of high prices of coal and its extreme national importance, no amount of waste, however small it may be, should be permitted to continue a moment longer than is necessary.

APPENDIX

Table I.—Properties of Saturated Steam

From tables by Messrs. L. S. Marks and H. N. Davis. Reproduced by permission of Messrs. Longmans, Green & Co.

Absolute Pressure lbs. per sq. in.	Gauge Pressure (approx.) lbs. per sq. in.	Temperature ° F.	Total Heat from Water at 32° F. in B.Th.U.	Heat in Liquid from 32° F in B.Th.U.	Latent Heat in B.Th.U.	Density of Weight per cu. ft. lbs.	Volume of 1 lb. in cu. ft.	Pressure in Atmosphere above vacuum.
1	—	101·83	1104·4	69·8	1034·6	0·00300	333·0	0·068
2	—	126·15	1115·0	94·0	1021·0	0·00576	173·5	0·136
3	—	141·52	1121·6	109·4	1012·3	0·00845	118·5	0·204
4	—	153·01	1126·5	120·9	1005·7	0·01107	90·5	0·272
5	—	162·28	1130·5	130·1	1000·3	0·01364	73·33	0·340
6	—	170·06	1133·7	137·9	995·8	0·01616	61·89	0·408
7	—	176·85	1136·5	144·7	991·8	0·01867	53·56	0·476
8	—	182·86	1139·0	150·8	988·2	0·02115	47·27	0·544
9	—	188·27	1141·1	156·2	985·0	0·02361	42·36	0·612
10	—	193·22	1143·1	161·1	982·0	0·02606	38·38	0·680
14·7	0	212	1150·4	180·0	970·4	0·03732	26·79	1·000
15	0·3	213·0	1150·7	181·0	969·7	0·03806	26·27	1·021
20	5	228·0	1156·2	196·0	960·0	0·04980	20·08	1·361
25	10	240·1	1160·4	208·0	952·0	0·06140	16·30	1·701
30	15	250·3	1163·9	218·8	945·1	0·0728	13·74	2·041
35	20	259·3	1166·8	227·9	938·9	0·0841	11·89	2·382
40	25	267·3	1169·4	236·1	933·3	0·0953	10·49	2·72
45	30	274·5	1171·6	243·4	928·2	0·1065	9·39	3·06
50	35	281·0	1173·6	250·1	923·5	0·1175	8·51	3·40
55	40	287·1	1175·4	256·3	919·0	0·1285	7·78	3·74
60	45	292·7	1177·0	262·1	914·9	0·1394	7·17	4·08
65	50	298·0	1178·5	267·5	911·0	0·1503	6·65	4·42
70	55	302·9	1179·8	272·6	907·2	0·1612	6·20	4·76
75	60	307·6	1181·1	277·4	903·7	0·1721	5·81	5·10
80	65	312·0	1182·3	282·0	900·3	0·1829	5·47	5·44
85	70	316·3	1183·4	286·3	897·1	0·1937	5·16	5·78
90	75	320·3	1184·4	290·5	893·9	0·2044	4·89	6·12
95	80	324·1	1185·4	294·5	890·9	0·2151	4·65	6·46
100	85	327·8	1186·3	298·3	888·0	0·2258	4·429	6·80
105	90	331·4	1187·2	302·0	885·2	0·2365	4·230	7·14
110	95	334·8	1188·0	305·5	882·5	0·2472	4·047	7·49
115	100	338·1	1188·8	309·0	879·8	0·2577	3·880	7·83
120	105	341·3	1189·6	312·3	877·2	0·2683	3·726	8·17
125	110	344·4	1190·3	315·5	874·7	0·2791	3·583	8·50
130	115	347·4	1191·0	318·6	872·3	0·2897	3·452	8·85
135	120	350·3	1191·6	321·7	869·9	0·3002	3·331	9·19
140	125	353·1	1192·2	324·6	867·6	0·3107	3·219	9·53
145	130	355·8	1192·8	327·4	865·4	0·3213	3·112	9·87
150	135	358·5	1193·4	330·2	863·2	0·3320	3·012	10·21
155	140	361·0	1194·0	332·9	861·0	0·3425	2·920	10·55
160	145	363·6	1194·5	335·6	858·8	0·3529	2·834	10·89
165	150	366·0	1195·0	338·2	856·8	0·3633	2·753	11·23
170	155	368·5	1195·4	340·7	854·7	0·3738	2·675	11·57
175	160	370·8	1195·9	343·2	852·7	0·3843	2·602	11·91
180	165	373·1	1196·4	345·6	850·8	0·3948	2·533	12·25
185	170	375·4	1196·8	348·0	848·8	0·4052	2·468	12·59
190	175	377·6	1197·3	350·4	846·9	0·4157	2·406	12·93
195	180	379·8	1197·7	352·7	845·0	0·4262	2·346	13·27
200	185	381·9	1198·1	354·9	843·2	0·437	2·290	13·61
205	190	384·0	1198·5	357·1	841·4	0·447	2·237	13·95
210	195	386·0	1198·8	359·2	839·6	0·457	2·187	14·29
215	200	388·0	1199·2	361·4	837·9	0·468	2·138	14·63
220	205	389·9	1199·6	363·4	836·2	0·478	2·091	14·97
225	210	391·9	1199·9	365·5	834·4	0·489	2·046	15·31
230	215	393·8	1200·2	367·5	832·8	0·499	2·004	15·65
235	220	395·6	1200·6	369·4	831·1	0·509	1·964	15·99
240	225	397·4	1200·9	371·4	829·5	0·520	1·924	16·33
245	230	399·3	1201·2	373·3	827·9	0·530	1·887	16·67
250	235	401·1	1201·5	375·2	826·2	0·541	1·850	17·01
260	245	404·5	1202·1	378·9	823·1	0·561	1·782	17·69
270	255	407·9	1202·6	382·5	820·1	0·582	1·718	18·37
280	265	411·2	1203·1	386·0	817·1	0·603	1·658	19·05
290	275	414·4	1203·6	389·4	814·2	0·624	1·602	19·73
300	285	417·5	1204·1	392·7	811·3	0·645	1·551	20·41

TABLE II.—SPECIFIC HEAT OF SUPERHEATED STEAM

Temperature of Superheated Steam °F.	Steam Pressure in lbs. per sq. in. in above Atmosphere.							
	50	75	100	125	150	175	200	250
400	0·50	0·52	0·55	0·58	0·60	0·64	0·67	0·75
420	0·50	0·52	0·54	0·57	0·57	0·63	0·65	0·72
440	0·50	0·51	0·54	0·56	0·56	0·61	0·64	0·69
460	0·50	0·51	0·54	0·56	0·56	0·59	0·62	0·66
480	0·49	0·51	0·53	0·55	0·55	0·58	0·60	0·64
500	0·49	0·51	0·53	0·55	0·55	0·58	0·59	0·62
525	0·49	0·51	0·53	0·54	0·54	0·56	0·58	0·61
550	0·49	0·51	0·52	0·54	0·54	0·56	0·57	0·60
575	0·49	0·50	0·52	0·53	0·53	0·55	0·56	0·59
600	0·49	0·50	0·52	0·53	0·53	0·55	0·56	0·58
625	0·49	0·50	0·52	0·53	0·53	0·54	0·55	0·58
650	0·49	0·50	0·51	0·52	0·52	0·54	0·55	0·57
675	0·49	0·50	0·51	0·52	0·52	0·54	0·55	0·57
700	0·49	0·50	0·51	0·52	0·52	0·54	0·55	0·56
725	0·49	0·50	0·51	0·52	0·52	0·53	0·54	0·56
750	0·49	0·50	0·51	0·52	0·52	0·53	0·54	0·56

Specific heat of superheated steam at atmospheric pressure = 0·48.

To use above table subtract the temperature corresponding to that of saturated steam (*see* Table I in Appendix) from the actual temperature of the superheated steam and multiply the remainder by the specific heat. The product *plus* the total heat of 1 lb. of saturated steam at the given pressure gives the total heat in 1 lb. of superheated steam at this pressure and temperature.

TABLE III.—APPROXIMATE SPECIFIC HEATS OF VARIOUS SUBSTANCES

Coal . . .	0·24	Cast iron . .	0·25	Air . . .	0·24
Coke . . .	0·20	,, steel . .	0·12	CO_2 . . .	0·22
Ashes . . .	0·17	Wrought iron .	0·11	CO . . .	0·25
Fire-bricks .	0·20	Copper . .	0·096	O	0·22
Water . . .	1·00	Flue gases . .	0·24	N	0·23

TABLE IV.—PROPERTIES OF WATER AT VARIOUS TEMPERATURES

Reproduced from *Useful Tables for Engineers and Steam Users*, by permission of Messrs. Babcock and Willcox, Ltd.

Water between 32° and 212° F.

Temp. ° F.	B.Th.U. per lb.	Weight per cu. ft. lbs.	Weight per gallon. lbs.	Temp. ° F.	B.Th.U. per lb.	Weight per cu. ft. lbs.	Weight per gallon. lbs.
32	0·00	62·42	10·0104	125	93·10	61·65	9·887
35	3·02	62·42	10·0104	130	98·14	61·56	9·873
40	8·06	62·42	10·0104	135	103·18	61·47	9·858
45	13·08	62·42	10·0104	140	108·22	61·37	9·842
50	18·10	62·41	10·0090	145	113·26	61·28	9·828
55	23·11	62·39	10·0060	150	118·30	61·18	9·812
60	28·12	62·37	10·0025	155	123·34	61·08	9·796
65	33·12	62·35	9·998	160	128·38	60·98	9·780
70	38·11	62·31	9·993	165	133·42	60·87	9·762
75	43·11	62·27	9·986	170	138·46	60·77	9·746
80	48·09	62·23	9·980	175	143·50	60·66	9·728
85	53·07	62·18	9·972	180	148·54	60·55	9·711
90	58·04	62·13	9·964	185	153·58	60·44	9·693
95	63·02	62·08	9·956	190	158·62	60·32	9·674
100	68·01	62·02	9·946	195	163·66	60·20	9·654
105	73·00	61·96	9·937	200	168·70	60·07	9·634
110	78·00	61·89	9·926	205	173·74	59·95	9·614
115	83·02	61·82	9·914	210	178·78	59·82	9·594
120	88·06	61·74	9·901	212	180·79	59·76	9·584

TABLE IV (*continued*)

Water between 212° and 406° F.

Temp. ° F.	Corresponding Steam Pressure by gauge. lbs. per sq. in.	Weight per cu. ft. lbs.	Weight per gallon. lbs.	Temp. ° F.	Corresponding Steam Pressure by gauge. lbs. per sq. in.	Weight per cu. ft. lbs	Weight per gallon. lbs.
212	0	59·760	9·584	337·7	100	55·949	8·973
215·4	1	59·741	9·581	340·8	105	55·837	8·955
218·6	2	59·659	9·568	343·9	110	55·727	8·937
221·6	3	59·580	9·555	346·9	115	55·620	8·920
224·5	4	59·503	9·543	349·8	120	55·515	8·903
227·2	5	59·431	9·531	352·5	125	55·412	8·887
229·8	6	59·361	9·520	355·4	130	55·311	8·870
232·3	7	59·293	9·509	358·0	135	55·214	8·855
234·7	8	59·227	9·498	360·7	140	55·116	8·840
237·1	9	59·161	9·488	363·2	145	55·023	8·824
239·4	10	59·097	9·478	365·7	150	54·931	8·809
241·6	11	59·035	9·468	368·1	155	54·841	8·795
243·7	12	58·975	9·458	370·5	160	54·725	8·776
247·8	14	58·858	9·439	372·8	165	54·668	8·767
251·6	16	58·748	9·422	375·0	170	54·584	8·754
255·2	18	58·643	9·403	377·2	175	54·503	8·741
258·6	20	58·541	9·388	379·3	180	54·422	8·729
266·5	25	58·304	9·350	381·4	185	54·342	8·715
273·9	30	58·078	9·314	383·5	190	54·262	8·702
280·6	35	57·869	9·302	385·7	195	54·182	8·689
286·5	40	57·680	9·250	387·7	200	54·102	8·677
292·1	45	57·501	9·222	389·7	205	54·026	8·664
297·5	50	57·325	9·193	391·7	210	53·941	8·651
302·5	55	57·162	9·167	393·5	215	53·876	8·640
307·2	60	57·003	9·142	395·5	220	53·803	8·630
311·6	65	56·855	9·118	397·3	225	53·733	8·617
315·9	70	56·709	9·095	399·1	230	53·664	8·606
319·8	75	56·571	9·072	400·9	235	53·596	8·595
323·8	80	56·437	9·051	402·6	240	53·529	8·585
328·1	85	56·311	9·031	404·2	245	53·462	8·574
331·0	90	56·186	9·011	406·0	250	53·396	8·563
334·4	95	56·065	8·991				

TABLE V.—FACTORS FOR CALCULATING THE EQUIVALENT EVAPORATION FROM AND AT 212° F. OF SATURATED STEAM AT VARIOUS STEAM PRESSURES AND FEED TEMPERATURES.

From tables partly by Mr. G. A. Rowell. Reproduced by permission of Messrs. Babcock and Willcox, Ltd.

Temp. of Feed Water°F.	Steam Pressure by Gauge in Pounds per square inch.												
	50	60	70	80	90	100	110	120	130	140	150	160	170
40	1·206	1·209	1·212	1·214	1·216	1·219	1·220	1·222	1·224	1·226	1·227	1·229	1·230
50	1·195	1·197	1·201	1·204	1·206	1·208	1·210	1·212	1·214	1·215	1·217	1·218	1·220
60	1·185	1·188	1·191	1·193	1·196	1·198	1·200	1·202	1·203	1·205	1·207	1·208	1·210
70	1·175	1·178	1·180	1·183	1·185	1·187	1·189	1·191	1·193	1·194	1·196	1·197	1·199
80	1·164	1·167	1·170	1·173	1·175	1·177	1·179	1·181	1·183	1·184	1·186	1·187	1·189
90	1·154	1·157	1·160	1·162	1·165	1·167	1·169	1·170	1·172	1·174	1·176	1·177	1·179
100	1·144	1·147	1·150	1·152	1·154	1·156	1·158	1·160	1·162	1·164	1·165	1·167	1·168
110	1·133	1·136	1·139	1·142	1·144	1·146	1·148	1·150	1·152	1·153	1·155	1·156	1·158
120	1·123	1·126	1·129	1·131	1·133	1·136	1·138	1·140	1·141	1·143	1·145	1·146	1·147
130	1·113	1·116	1·118	1·121	1·123	1·125	1·127	1·129	1·130	1·132	1·134	1·136	1·137
140	1·102	1·105	1·108	1·110	1·113	1·115	1·117	1·119	1·120	1·122	1·124	1·125	1·127
150	1·091	1·095	1·098	1·100	1·102	1·104	1·106	1·108	1·110	1·111	1·113	1·115	1·116
160	1·081	1·084	1·087	1·090	1·092	1·094	1·096	1·098	1·100	1·101	1·103	1·104	1·106
170	1·070	1·074	1·077	1·079	1·081	1·083	1·085	1·087	1·089	1·091	1·092	1·094	1·095
180	1·060	1·063	1·066	1·069	1·071	1·073	1·075	1·077	1·079	1·080	1·082	1·083	1·085
190	1·050	1·053	1·056	1·058	1·060	1·063	1·065	1·066	1·068	1·070	1·071	1·073	1·074
200	1·039	1·043	1·045	1·048	1·050	1·052	1·054	1·056	1·058	1·059	1·061	1·063	1·064

Temp. of Feed Water°F.	Steam Pressure by Gauge in Pounds per square inch.												
	180	190	200	210	220	230	240	250	260	270	280	290	300
40	1·232	1·233	1·234	1·236	1·237	1·238	1·239	1·240	1·241	1·242	1·243	1·244	1·245
50	1·221	1·223	1·224	1·225	1·226	1·228	1·229	1·230	1·231	1·232	1·233	1·234	1·235
60	1·211	1·212	1·214	1·215	1·216	1·217	1·218	1·219	1·220	1·221	1·222	1·223	1·224
70	1·200	1·202	1·203	1·205	1·206	1·207	1·208	1·209	1·210	1·211	1·212	1·213	1·214
80	1·190	1·192	1·193	1·194	1·195	1·196	1·198	1·199	1·200	1·201	1·202	1·203	1·204
90	1·180	1·181	1·183	1·184	1·185	1·186	1·187	1·188	1·189	1·190	1·191	1·192	1·193
100	1·170	1·171	1·172	1·174	1·175	1·176	1·177	1·178	1·179	1·180	1·181	1·182	1·183
110	1·159	1·160	1·162	1·163	1·164	1·166	1·167	1·168	1·169	1·170	1·171	1·172	1·173
120	1·149	1·150	1·151	1·153	1·154	1·155	1·156	1·157	1·158	1·159	1·160	1·161	1·162
130	1·138	1·140	1·141	1·142	1·144	1·145	1·146	1·147	1·148	1·149	1·150	1·151	1·152
140	1·128	1·129	1·131	1·132	1·133	1·134	1·135	1·136	1·137	1·138	1·139	1·140	1·141
150	1·118	1·119	1·120	1·121	1·123	1·124	1·125	1·126	1·127	1·128	1·129	1·130	1·131
160	1·107	1·108	1·110	1·111	1·112	1·113	1·115	1·116	1·117	1·118	1·119	1·120	1·121
170	1·097	1·098	1·099	1·101	1·102	1·103	1·104	1·105	1·106	1·107	1·108	1·109	1·110
180	1·086	1·088	1·089	1·090	1·091	1·093	1·094	1·095	1·096	1·097	1·098	1·099	1·100
190	1·076	1·077	1·078	1·080	1·081	1·082	1·083	1·084	1·085	1·086	1·087	1·088	1·089
200	1·065	1·067	1·068	1·069	1·071	1·072	1·073	1·074	1·075	1·076	1·077	1·078	1·079

TABLE VI.—MELTING POINTS OF METALS IN DEGREES F.

Tin	449° F.	Silver	1761° F.
Bismuth	520° F.	Copper	1982° F.
Lead	621° F.	Nickel	2646° F.
Zinc	787° F.	Cobalt	2714° F.
Antimony	1166° F.	Iron (pure)	2768° F.
Aluminium	1218° F.	Palladium	2820° F.

TABLE VII.—SHOWING THE PERCENTAGE OF FUEL SAVED BY INCREASING THE EFFICIENCY OF A BOILER PLANT

Initial Efficiency %.	Final Efficiency Obtained %.								
	45	50	55	60	65	70	75	80	85
40	11·2	20	27·2	33·3	38·5	42·8	46·7	50·0	52·9
45	—	10	18·2	25	30·8	35·7	40·0	43·8	47·1
50	—	—	9·2	16·7	23·1	28·6	33·3	37·5	41·2
55	—	—	—	8·3	15·3	21·3	26·7	31·3	35·3
60	—	—	—	—	7·7	14·3	20·0	25·0	29·4
65	—	—	—	—	—	7·2	13·3	18·8	23·6
70	—	—	—	—	—	—	6·7	12·5	17·7
75	—	—	—	—	—	—	—	6·3	11·8
80	—	—	—	—	—	—	—	—	5·8

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